(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 072 795 A1

(12) # EUROPEAN PATENT APPLICATION
published in accordance with Art. 158(3) EPC

(43) Date of publication:
**31.01.2001 Bulletin 2001/05**

(21) Application number: **99912058.7**

(22) Date of filing: **31.03.1999**

(51) Int. Cl.$^{7}$: **F04B 51/00**

(86) International application number:
**PCT/JP99/01661**

(87) International publication number:
**WO 99/51883 (14.10.1999 Gazette 1999/41)**

(84) Designated Contracting States:
**DE DK FR GB IT**

(30) Priority: **03.04.1998 JP 10858898**
**10.06.1998 JP 17812098**
**30.09.1998 JP 27918998**
**30.10.1998 JP 31057598**

(71) Applicant: **EBARA CORPORATION**
**Ohta-ku, Tokyo 144-8510 (JP)**

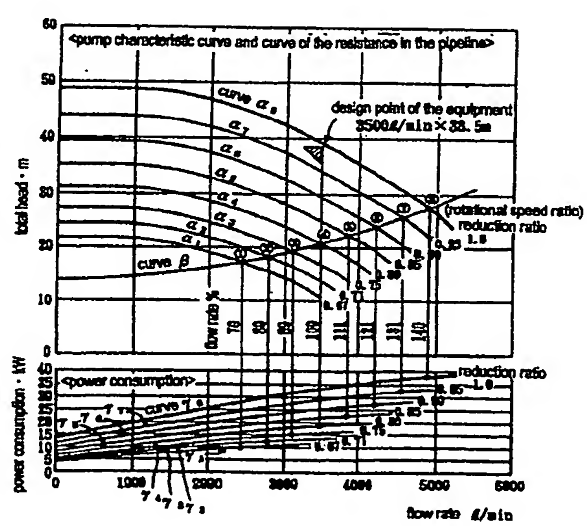
(72) Inventors:
- **YAMAMOTO, Masakazu-Ebara Corporation**
**Ohta-ku, Tokyo 144-8510 (JP)**
- **MIYAKE, Yoshio-Ebara Corporation**
**Ohta-ku, Tokyo 144-8510 (JP)**
- **KAWABATA, Junya-Ebara Corporation**
**Ohta-ku, Tokyo 144-8510 (JP)**
- **UWAI, Keita-Ebara Corporation**
**Ohta-ku, Tokyo 144-8510 (JP)**
- **MIYAZAKI, Yoshiaki-Ebara Corporation**
**Ohta-ku, Tokyo 144-8510 (JP)**
- **IIJIMA, Katsuji-Ebara Corporation**
**Ohta-ku, Tokyo 144-8510 (JP)**
- **TAMAI, Hiromi-Ebara Corporation**
**Ohta-ku, Tokyo 144-8510 (JP)**

(74) Representative:
**Wagner, Karl H., Dipl.-Ing.**
**Wagner & Geyer,**
**Patentanwälte,**
**Gewürzmühlstrasse 5**
**80538 München (DE)**

(54) **DIAGNOSING SYSTEM FOR FLUID MACHINERY**

(57) The present invention relates to a diagnostic system for fluid machinery capable of detecting wasteful energy consumption in the fluid machinery. The diagnostic system comprises a first identifying means for identifying the characteristics of the fluid machinery represented by flow rate-head characteristics by inputting prescribed data on the fluid machinery to be diagnosed; a second identifying means for identifying the operating flow rate or operating pressure of the fluid machinery according to the relationship between the identified characteristics and a measured operating pressure or operating flow rate of the fluid machinery by operating the fluid machinery to be diagnosed and inputting the measured results of the operating pressure (head), operating flow rate, power consumption, or operating electric current of the fluid machinery in operation; and a processing means for computing variations in the operating flow rate, operating pressure, or power consumption when the rotational speed of the fluid machinery to be diagnosed is varied and for displaying the computed results.

*F I G. 12*




EP 1 072 795 A1

**Best Available Copy**

## Description

### Technical Field

[0001] The present invention relates to a diagnostic system for fluid machinery capable of estimating wasteful energy consumption in the fluid machinery and its peripheral devices, and more particularly to a system for estimating and verifying the minimum required power consumption in equipment using a cooling water circulating pump or the like.

### Background Art

[0002] A technology for controlling a rotational speed of a motor pump using an inverter (frequency converter) is known in the art. This method is an extremely effective means for energy saving, not only in the application of the pump for a feed water supply system or the like in which a violent fluctuation of load occurs, but also in the application of the circulating pump or the like.

[0003] A general-purpose pump is not manufactured according to a standard specification. Specifically, the general-purpose pump is not manufactured so as to meet a certain specification (flow rate, pump head), but such a pump having a performance exceeding the required specification is selected front a stock. Additionally, design specifications are generally calculated so as to satisfy a maximum flow rate with plenty of margin of flow rate. The energy loss in piping is also determined in consideration of margin and aged deterioration. Accordingly, when the pump is actually operated, the valve adjustment is conducted for suppressing excessive flow rate, resulting in a waste of the energy. Even if the pump is selected based on calculations, waste of energy will be more or less generated.

[0004] A decisive factor of saving energy is to match the operations of the pump to "true" requirements in order to conduct efficient operations without energy loss. Here, "true" requirements are defined as the minimum required flow rate and head that can only be found by performing actual operations at the site.

[0005] For example, if too much margin is found in the capacity of the pump when performing actual operations at the site, it is possible to save energy by the following methods.

(1) Replacing the pump with a smaller one having one rank reduced capacity.
(2) Machining the outer diameter of the impeller to reduce the performance of the pump to an appropriate value.

[0006] However, this process requires an extra expense. Also, after performing the above measure, it is difficult to raise the performance (recover the performance) when needed. On the other hand, an inverter can easily and reversibly adjust the pump performance, thus achieving operations having the best energy efficiency.

[0007] In case of achieving energy-saving by adding an inverter to an existing pump, there are several methods, each with its advantages and disadvantages, described below.

(1) Controlling an existing motor pump with an inverter

[0008]

(Advantage) No modifications are required for the motor pump itself.
(Disadvantage) The area around the pump is likely to have a lot of moisture, and such area is unsuitable for installation of a general inverter. Accordingly, it is desirable that the inverter is housed inside the control panel. Hence, in addition to installation of the inverter, it is necessary to modify the control panel or manufacture a new control panel.

(2) Replacing an existing motor pump with an inverter-mounted pump

[0009]

(Advantage) Essentially no modifications of the control panel or the like are necessary.
(Disadvantage) An existing pump is required to be replaced in its entirety. Therefore, since the existing pump that has not fulfilled its service life is replaced, this method is disadvantageous from the viewpoint of cost.

(3) Replacing only a motor of an existing motor pump with an inverter-mounted motor

[0010]

(Advantage) Only the motor of the pump is replaced. However, if the pump is not a direct coupling type, essentially

the pump assembly must be disassembled and reassembled. Essentially no modifications of the control panel are necessary.

(Disadvantage) Since the motor that has not fulfilled its service life is replaced, this method is disadvantageous from the viewpoint of cost.

[0011] Therefore, it is necessary to select the most effective method based on the conditions at each site.

[0012] An even greater problem is the lack of a common method for calculating the amount of energy conservation achieved by using an inverter. That is, no method has been established for finding the "true" requirements of a pump when an inverter is not used and for estimating and verifying the difference between these values and the actual operating point. For this reason, even though it is known that an inverter contributes to energy conservation, how much energy can be conserved cannot be learned. As a result, the return of investment of replacing an existing pump with an inverter-mounted pump, for example, cannot be calculated. This has prevented such energy conservation equipment from being permeated through the market.

[0013] As shown in FIG. 42, the flow rate-pressure characteristics (Q-H characteristics) of a centrifugal pump are represented by a single curved line when the horizontal axis represents flow rate (discharge flow rate) and the vertical axis represents total head (pressure). According to the situation, other data such as pump shaft power (output), pump efficiency, suction performance (required NPSH), and electric current (in case of motor pumps) may be represented.

[0014] As described above, there has been known a technology for controlling a rotational speed of a motor pump using equipment, such as an inverter (frequency converter), for changing the rotational speed of the fluid machinery. This method is an extremely effective method for saving energy, not only in the application of the pump for a feed water system or the like in which a violent fluctuation of load occurs, but also in the application of the circulating pump or the like.

[0015] As described above, a general-purpose pump is not manufactured according to a standard specification. Specifically, the general-purpose pump is not manufactured so as to meet a certain specification (flow rate, pump head), but such a pump having a performance exceeding the required specification is selected from a stock. A decisive factor of conserving energy is to match the operation point of the pump to the "true" requirements in order to conduct efficient operations without energy loss. Here, "true" requirements are defined as the minimum required flow rate and head that can be found only by performing actual operations at the site. A remarkable amount of energy can be saved by reducing the rotational speed of the pump with an inverter.

[0016] There have also been proposed pumps having an inverter in which the frequency applied to the pump can be controlled stepwise with an adjusting knob. As shown in FIGS. 43A and 43B, in this type of pump, the Q-H characteristics are represented by a plurality of curves showing the relationship between the flow rate (discharge flow rate) and total head (pressure) when the frequency (rotational speed) is varied according to each number on the adjusting knob. FIG. 43A is a partial enlarged view, and FIG. 43B is a total view.

[0017] However, in the conventional technology representing characteristics as shown in FIG. 42, even if an inverter is used to conserve energy, it is not possible to see the relationship between discharge flow rate and total head when varying the rotational speed of the pump. Further, the graph contains no data related to power consumption. As a result, it is necessary to perform a bothersome simulation every time in order to find the return of investment or cost-effectiveness for installing an inverter.

[0018] Although the output for each rotational speed corresponding to each number on the adjusting knob is included in the conventional technology representing characteristics as shown in FIGS. 43A and 43B, the graph contains no data related to power consumption. Thus, it is necessary to acquire separate data such as motor efficiency and inverter efficiency and perform a simulation in order to learn how much energy is saved when varying the rotational speed.

[0019] In other words, much time and effort is currently required in the conventional technology to calculate the return of investment when using an inverter in a pump to save energy. Further, the energy conserving benefits of using pumps with inverters have not gained widespread popularity at present.

## Disclosure of Invention

[0020] In view of the foregoing, it is a first object of the present invention to provide a diagnostic system for fluid machinery capable of estimating the amount of energy conservation that can be achieved using an inverter (frequency converter) to adjust a rotational speed of the fluid machinery before performing such adjustments. In other words, the first object of the present invention is to provide a diagnostic system for fluid machinery capable of finding wasteful energy consumption in the fluid machinery and its peripheral devices.

[0021] It is a second object of the present invention to provide an energy-saving pre-diagnostic system for conserving energy in fluid machinery capable of easily calculating the amount of energy conservation that can be achieved using an inverter (frequency converter) to adjust a rotational speed of the fluid machinery.

[0022] It is a third object of the present invention to provide a method and material for displaying the characteristics of fluid machinery that are capable of easily finding the return of investment when incorporating (adding) an inverter or the like by including data related to power consumption in case of varying rotational speeds of fluid machinery such as a pump, and can aid in making energy-conserving products more widespread in the market.

[0023] In order to achieve the first object, the diagnostic system for fluid machinery of the present invention has aspects described in (1)-(4) below.

(1) A diagnostic system for fluid machinery comprises first identifying means for inputting prescribed data on the fluid machinery to be diagnosed and identifying the characteristics of the fluid machinery represented by flow rate-head characteristics; second identifying means for identifying the operating flow rate or operating pressure of the fluid machinery according to the relationship between the identified characteristics of the fluid machinery and a measured operating pressure or operating flow rate of the fluid machinery by operating the fluid machinery to be diagnosed and inputting the measured results of the operating pressure (head), operating flow rate, power consumption, or operating electric current of the fluid machinery in operation; and processing means for computing variations in the operating flow rate, operating pressure, or power consumption while the rotational speed of the fluid machinery to be diagnosed is varied, and for displaying the computed results.

(2) A recording medium is capable of being read by a computer for storing programs to enable the computer to implement the functions of: identifying the characteristics of the fluid machinery represented by flow rate-head characteristics by inputting prescribed data on the fluid machinery to be diagnosed; identifying the operating flow rate or operating pressure of the fluid machinery according to the relationship between the identified characteristics and a measured operating pressure or operating flow rate of the fluid machinery by operating the fluid machinery to be diagnosed and inputting the measured results of the operating pressure (head), operating flow rate, power consumption, or operating electric current of the fluid machinery in operation; and computing variations in the operating flow rate, operating pressure, or power consumption when the rotational speed of the fluid machinery to be diagnosed is varied, and displaying the computed results.

(3) A diagnostic system for fluid machinery comprises first identifying means for identifying the characteristics of the fluid machinery represented by flow rate-head characteristics of the fluid machinery to be diagnosed; second identifying means for identifying the actual operating point of the fluid machinery to be diagnosed; and processing means for computing variations in the operating point when the rotational speed of the fluid machinery to be diagnosed is varied, and for displaying the computed results.

(4) A method for diagnosing fluid machinery comprises identifying the characteristics of the fluid machinery represented by the flow rate-head characteristics of the fluid machinery to be diagnosed; identifying the actual operating point of the fluid machinery to be diagnosed; computing variations in the operating point when the rotational speed of the fluid machinery to be diagnosed is varied; and displaying the computed results.

[0024] According to the above aspects (1)-(4) of the present invention, the amount of energy that can be saved by adjusting the rotational speed with an inverter (frequency converter) can be calculated prior to performing the adjustment.

[0025] Each of the means and each of the steps in the present invention are implemented by a computer, such as a programmed personal computer. However, some of the steps in the above aspect (4) of the present invention include cases that are not executed by a computer but are executed by other means (manual operations, etc.).

[0026] In order to achieve the first object, according to another aspect of the present invention, there is provided a method for identifying characteristics of fluid machinery comprising: calculating the head and shaft power for flow rates by determining representative points for characteristics of fluid machinery including a representative head and representative shaft power and by determining the ratios of head and shaft power other than the representative flow rate to the representative head and representative shaft power based on the port diameter of the fluid machinery, the number of impeller stages, and the rated output and rated rotational speed of the motor used to drive the fluid machinery; estimating provisional characteristics of the fluid machinery based on the calculated head and shaft power; and identifying characteristics of the fluid machinery and the operating point including the operating flow rate by correcting the provisional characteristics of the fluid machinery based on measurement data including at least the head and power consumption during current operations.

[0027] In order to achieve the second object, according to the first aspect of the present invention, there is provided an energy-saving pre-diagnostic system for fluid machinery, comprising: inputting means for inputting flow rate-pressure (head) and flow rate-power consumption data for fluid machinery having a motor driven by a commercial AC power, and design specifications (flow rate-pressure) in a facility side; inputting or estimating means for inputting or estimating resistance of piping (actual head) when the flow rate is zero; calculating means for calculating the reduction in power consumption achieved when reducing the rotational speed of the fluid machinery with a frequency converter; and processing means for displaying the calculated results.

[0028] According to another aspect of the present invention, there is provided a recording medium capable of being read by a computer for storing programs to enable the computer to implement the functions of: inputting flow rate-pressure (head) and flow rate-power consumption data for fluid machinery having a motor driven by a commercial AC power, and design specifications (flow rate-pressure) in a facility side; inputting or estimating resistance of piping (actual head) when the flow rate is zero; calculating the reduction in power consumption achieved when reducing the rotational speed of the fluid machinery with a frequency converter; and displaying the calculated results.

[0029] In order to achieve the third object of the present invention, the present invention has aspects described in (1)-(5).

(1) A method for displaying the characteristics of fluid machinery, comprises displaying the flow rate-pressure characteristics of the fluid machinery varied according to the rotational speed on the same surface using a plurality of curves; and displaying data related to the power consumption on the same surface.

According to the present invention, it is easy to find the return of investment when incorporating an inverter, for example, because data related to power consumption can be seen simultaneously with the flow rate-pressure characteristics of the fluid machinery for varied rotational speeds.

(2) A display material is provided for displaying the characteristics of the fluid machinery using the method described in the above (1). This display material can be a sales brochure, such as a catalog.

(3) A fluid machinery or an apparatus for varying the rotational speed of the fluid machinery, comprises displaying the flow rate-pressure characteristics of the fluid machinery varied according to the rotational speed on the same surface of a promotional material represented by a catalog, using a plurality of curves; and displaying data related to the power consumption on the same surface of the promotional material.

With this construction, the return of investment can be easily viewed on a sales brochure or the like when introducing a fluid machinery or apparatus for varying the rotational speed of the fluid machinery, such as an inverter.

(4) A line graph for the power-consumption of fluid machinery comprises a plurality of curves indicating the flow rate-pressure characteristics of fluid machinery in each of rotational speeds and displayed in a coordinate system; and a plurality of curves indicating the flow rate-pressure characteristics of the fluid machinery in each of values of power consumption and displayed in the coordinate system.

(5) A calculating and graphing system, comprises a computer for obtaining the display material of claim 28 or the line graph of claim 30, by inputting data for the flow rate-pressure characteristics and flow rate-power consumption characteristics of fluid machinery having a motor driven by a commercial AC power. Further, a recording medium is capable of being read by a computer for storing programs to enable the computer to implement the calculating and graphing system.

## Brief Description of Drawings

[0030]

FIG. 1 is a block diagram showing the hardware configuration of a diagnostic system for fluid machinery according to the present invention;

FIG. 2 is a graph showing characteristic curves for the fluid machinery to describe the process of the diagnostic system;

FIGS. 3A and 3B are graphs showing characteristic curves for the fluid machinery to describe the process of the diagnostic system;

FIGS. 4A and 4B are graphs showing characteristic curves for the fluid machinery to describe the process of the diagnostic system;

FIGS. 5A and 5B are graphs showing characteristic curves for the fluid machinery to describe the process of the diagnostic system;

FIG. 6 is a graph showing characteristic curves for the fluid machinery to describe the process of the diagnostic system;

FIG. 7 is a graph showing characteristic curves for the fluid machinery to describe the process of the diagnostic system;

FIG. 8 is a graph showing characteristic curves for the fluid machinery to describe the process of the diagnostic system;

FIG. 9 is a graph showing characteristic curves for the fluid machinery to describe the process of the diagnostic system;

FIG. 10 is a graph showing characteristic curves for the fluid machinery to describe the process of the diagnostic system;

FIG. 11 is a graph showing characteristic curves for the fluid machinery to describe the process of the diagnostic

system;

FIG. 12 is a graph showing characteristic curves for the fluid machinery to describe the process of the diagnostic system;

FIG. 13 is a flowchart showing the general process flow performed in the diagnostic system for fluid machinery shown in FIGS. 1 through 12;

FIG. 14 is a side view showing a mounting configuration of a performance regulating apparatus for fluid machinery according to a first embodiment;

FIG. 15 is a side view showing a mounting configuration of a performance regulating apparatus for fluid machinery according to a second embodiment;

FIGS. 16A and 16B are views showing a detailed structure of the performance regulating apparatus shown in FIG. 14, and FIG. 16A is a front view with a partially cross-sectional part and FIG. 16B is a side view;

FIG. 17 is a cross-sectional view taken along line XVII-XVII of FIG. 16A;

FIGS. 18A and 18B are views showing a detailed structure of the mounting configuration used with a performance regulating apparatus shown in FIG. 15, and FIG. 18A is a front view with a partially cross-sectional part and FIG. 18B is a plan view;

FIG. 19 is a cross-sectional view taken along line XIX-XIX of FIG. 18A;

FIGS. 20A and 20B are views showing a mounting configuration used with a performance regulating apparatus for fluid machinery according to a third embodiment, and FIG. 20A is a side view and FIG. 20B is a view as viewed from an arrow XX of FIG. 20A;

FIGS. 21A and 21B are views showing another embodiment of the mounting configuration used with a performance regulating apparatus for fluid machinery shown in FIGS. 14 through 20, and FIG. 21A is a front view and FIG. 21B is a side view;

FIG. 22 is a graph showing characteristic curves for the fluid machinery to describe the process of the diagnostic system;

FIG. 23 is a schematic view showing an example of the diagnostic system that can be brought to the work site of the fluid machinery;

FIG. 24 is a graph showing dimensionless pump characteristics (flow rate-head and flow rate-shaft power) for specific speeds;

FIG. 25 is a graph showing a specific speed-pump efficiency characteristic curve;

FIGS. 26A through 26D are views showing the stages of estimating provisional pump characteristics, identifying the operating point (flow rate), and correcting the provisional characteristics using flow rate calculated from the head and power consumption during current operations and estimated values of the efficiency of the fluid machinery and efficiency of the motor;

FIGS. 27A through 27D are views showing the stages of estimating provisional pump characteristics, identifying the operating point (flow rate), and correcting the provisional characteristics using flow rate calculated from the head and the power consumption during current operations and estimated values of the efficiency of the fluid machinery and the efficiency of the motor, and the head and the power consumption during shutoff operations;

FIGS. 28A through 28D are views showing the stages of estimating provisional pump characteristics, identifying the operating point (flow rate), and correcting the provisional characteristics using flow rate calculated from the head and the power consumption during current operations and estimated values of the efficiency of the fluid machinery and the efficiency of the motor, and the head and the power consumption during operations when the valve is fully open;

FIGS. 29A through 29D are views showing the stages of estimating provisional pump characteristics, identifying the operating point (flow rate), and correcting the provisional characteristics using flow rate calculated from the head and the power consumption during current operations and estimated values of the efficiency of the fluid machinery and the efficiency of the motor, and the head and the power consumption during both shutoff operations and operations when the valve is fully open;

FIGS. 30A through 30D are views showing the stages of estimating provisional pump characteristics, identifying the operating point (flow rate), and correcting the provisional characteristics, wherein the operating point (flow rate) is identified from the provisional characteristics and the head during current operations, while the provisional characteristics are corrected according to the current power consumption;

FIGS. 31A through 31D are views showing the stages of estimating provisional pump characteristics, identifying the operating point (flow rate), and correcting the provisional characteristics, wherein the operating point (flow rate) is identified from the provisional characteristics and the head during current operations, while the provisional characteristics are corrected according to the current power consumption and the head and power consumption when the valve is fully open;

FIG. 32 is a graph showing characteristic curves for the fluid machinery to describe the process of an energy-saving pre-diagnostic system for fluid machinery according to the present invention;

FIG. 33 is a graph showing characteristic curves for the fluid machinery to describe the process of an energy-saving pre-diagnostic system for fluid machinery;

FIG. 34 is a view showing the output indicative of diagnostic results from an energy-saving pre-diagnostic system for fluid machinery;

FIG. 35 is a table showing the area A of FIG. 34;

FIG. 36 is a schematic view showing an example of the energy-saving pre-diagnostic system for fluid machinery employing a personal computer;

FIG. 37 is a graph showing the characteristics of the fluid machinery in a method and material for displaying the characteristics according to a first embodiment of the present invention;

FIG. 38 is a graph showing an example of a trial calculation of the return of investment in case of introducing an inverter;

FIG. 39 is a graph showing the characteristics of the fluid machinery in a method and material for displaying the characteristics according to a second embodiment;

FIG. 40 is a graph showing the characteristics of the fluid machinery in a method and material for displaying the characteristics according to a third embodiment;

FIG. 41 is a flowchart showing the general process flow performed in a calculating and graphing system;

FIG. 42 is a graph showing an example of display of a pump performance curve according to the prior art; and

FIGS. 43A and 43B are graphs showing another example of display of pump performance curves according to the prior art.

## Best Mode for Carrying Out the Invention

**[0031]** A diagnostic system for fluid machinery according to preferred embodiments of the present invention will be described with reference to the accompanying drawings.

**[0032]** A diagnostic system for fluid machinery comprises a first identifying means for identifying the characteristics of the fluid machinery represented by flow rate-head characteristics by inputting specified data on the fluid machinery to be diagnosed; a second identifying means for identifying the operating flow rate or operating pressure of the fluid machinery according to the relationship between the identified characteristics and a measured operating pressure or operating flow rate of the fluid machinery by operating the fluid machinery to be diagnosed and inputting the measured results of the operating pressure (head), operating flow rate, power consumption, or operating electric current of the fluid machinery in operation; and a processing means for computing variations in the operating flow rate, operating pressure, or power consumption when the rotational speed of the fluid machinery to be diagnosed is changed and for displaying the computed results.

**[0033]** FIG. 1 shows the hardware configuration of the diagnostic system for fluid machinery according to the present embodiment. In the present embodiment, a pump will be described as an example of the fluid machinery.

**[0034]** The diagnostic system for fluid machinery comprises a main controller 1 for controlling the overall system, and a main storage unit 2 connected to the main controller 1. The main controller 1 comprises a control unit 3 and an arithmetic unit 4. The main controller 1 is also connected to an input device 5 including a keyboard, mouse, or the like and an output device 6 including a printer, display, or the like. In FIG. 1, bold arrows show the flow of data and programs, while the thin arrows show the flow of control signals.

**[0035]** The main controller 1 has an internal memory (not shown) for storing control programs such as an operating system, a program prescribing the diagnostic procedure for the fluid machinery, and required data, and these programs implement the first identifying means, the second identifying means and the processing means. The main storage unit 2 comprises a hard disk, floppy disk, optical disk, or the like and stores data for various models of pumps currently appearing on the market. This data does not necessarily have to be accurate for each pump. The data may be averaged data or modeled element data for identifying the pump characteristics with a certain degree of accuracy by inputting a port diameter or output.

**[0036]** According to the present invention, by the first identifying means incorporated in the main controller 1, it is possible to identify, for example, the characteristics of the motor pump to be diagnosed. More specifically, the following example values on the pump rating plate (or nameplate) are referenced and inputted into the input device 5.

- Port diameter of pump
- Rated output of motor (or nominal output of pump)
- Number of poles of motor
- Operating frequency of motor
- Number of impeller stages

The first identifying means identifies the flow rate-head characteristics and flow rate-power consumption characteristics

of the pump on the basis of the above data. This identification can be made by selecting data stored in the main storage unit 2 that most closely resembles the referenced data. In addition to the above data, the rating plate specifications, model name, the number of impeller stages, outer diameter of the impeller, pump test data, and the like are included in data inputted into the input device 5.

**[0037]** Identified characteristics are displayed with one solid line, broken lines and diagonal lines as shown in FIG. 2. FIG. 2 shows the flow rate-head characteristics and flow rate-power consumption characteristics of the pump, where the horizontal axis represents flow rate (Q) and the vertical axis represents head (H) or power consumption (W). As shown in FIG. 2, the first identifying means identifies the flow rate-head characteristics and flow rate-power consumption characteristics of the pump with a prescribed width based on the input results. Hence, the region of a diagonal line portion *a* is identified. The broken lines represent the upper and lower limits of the diagonal line portion *a*, while the solid line is a centerline of the area shown by the diagonal line portion *a*. The identified results by the first identifying means are displayed on the output device 6, which includes a liquid crystal display or the like. The diagonal line portion *a* is refined on the basis of input data and becomes narrower in area. For example, the characteristics can be identified with higher accuracy if the manufacturer and model name of the pump are known, and hence, the area of the diagonal line portion a can be minimized, as shown in the progression from FIG. 3A to FIG. 3B.

**[0038]** The results of identification by the first identifying means are further refined by inputting the power consumption of the fluid machinery at the actual operating point. That is, the power consumption of the motor during actual operations is measured and the result is inputted into the input device 5 to refine the identification. Here, the region of the diagonal line portion *a* is revised to include the value of actual power consumption for the motor, as shown in the progression from FIG. 4A to FIG 4B

**[0039]** The results of identification by the first identifying means are further refined by inputting the operating pressure and power consumption during actual shutoff operations, as illustrated in the progression from FIG. 5A to FIG. 5B. Specifically, the diagonal line portion a is corrected to include the values of the operating pressure and power consumption during actual shutoff operations.

**[0040]** The results of identification by the first identifying means may be corrected further by inputting test data (flow rate-head and flow rate-power consumption) for the pump obtained in the factory prior to shipment, for example. In this case, it is possible to identify the characteristics of the pump with a very high degree of accuracy, as shown in FIG. 6. Actually, an identification near the accuracy of that shown in FIG. 6 may be possible by inputting only some of the above data without requiring input of test data for the pump. In this case, it is possible to obtain an identification similar to that of FIG. 6 by selecting the centerline through the area of the diagonal line portion *a* after achieving the refinement shown in FIG. 5B.

**[0041]** By using the second identifying means on the pump characteristics identified by the first identifying means, it is possible to identify the operating point of the pump in this facility or equipment. Identification by the second identifying means is performed by operating the pump to be diagnosed; measuring the actual operating pressure (head), operating flow rate, or power consumption; and inputting this measurement into the input device 5.

(1) In case of inputting the operating pressure

**[0042]** The operating pressure is calculated by measuring the suction pressure and discharge pressure of the pump. By inputting the operating pressure, it is possible to identify the operating flow rate and power consumption, as shown in FIG. 7, by finding an intersecting point between the flow rate-head characteristic curve and the flow rate-power consumption characteristic curve.

(2) In case of inputting the operating flow rate

**[0043]** The operating flow rate is measured with a flow meter. By inputting the operating flow rate, it is possible to identify the operating pressure (head) and power consumption, as shown in FIG. 8, by finding an intersecting point between the flow rate-head characteristic curve and the flow rate-power consumption characteristic curve.

(3) In case of inputting power consumption

**[0044]** The power consumption of the motor during operations is measured with a wattmeter. By inputting the power consumption, it is possible to identify the operating pressure (head) and operating flow rate, as shown in FIG. 9, by finding an intersecting point between the flow rate-head characteristic curve and the flow rate-power consumption characteristic curve. The operating current of the motor can also be measured and inputted in place of the power consumption data.

**[0045]** Actually, however, expensive measuring equipment is required to measure flow rate and power consumption, and such work is time-consuming. The operating pressure, on the other hand, can be easily calculated simply by

attaching a compound pressure gauge to the suction side of the pump and a pressure gauge to the discharge side of the pump.

**[0046]** It is convenient to find the actual head and input this value before utilizing the processing means. This is because it is possible to calculate the system head curve on the facility side (piping side) with the actual head. The following expressions are in relation to FIG. 10.

$$H_1 - H_0 = K_1 Q_1^{\;2}$$

**[0047]** Therefore, $K_1 = (H_1 - H,) / Q_1^{\;2}$, where $H_1$ is the total head, $H_0$ is the actual head, and $Q_1$ is the flow rate.

**[0048]** Hence, by identifying $Q_1$, $H_1$, and $H_0$, it is possible to find $K_1$.

**[0049]** Therefore, the resistance F on the facility side (piping side) can be found for any flow rate Q, as follows:

$$F = H_0 + K_1 Q^2 = H_0 + (H_1 - H_0)\,(Q/Q_1)^2$$

The actual head can be accurately determined with a controller described later. If it is difficult to find the actual head, it is possible to input provisional values for approximately three types of actual heads, represented by models 1, 2, and 3 in FIG. 11.

**[0050]** Next, the function of the processing means will be described.

**[0051]** In FIG. 12, the curve $\alpha_8$ shows the flow rate-head characteristics of a pump identified by the first identifying means. The curve $\alpha_8$ includes a plurality of points which are not shown. The coordinates of these points are defined by flow rate and head, as in $(q_1, h_1)$, $(q_2, h_2)$, ....

**[0052]** The processing means establishes a rotational speed ratio for these points. If the rotational speed ratio is 0.95, for example, then $q_1$ is shifted to $q_1 \times 0.95$ and $h_1$ is shifted to $h_1 \times 0.95^2$. This generates the points $(0.95q_1, 0.95^2h_1)$, $(0.95q_2, 0.95^2h_2)$, .... The curve $\alpha_7$ is the line connecting these points. This process is repeated for rotational speed ratios of 0.90, 0.85, 0.80, ... to form curves $\alpha_6$-$\alpha_1$.

**[0053]** The curve $\beta$ is the system head curve on the facility side (piping side) calculated by the above-described method shown in FIG. 10. The point denoted by (8) in the drawing is the actual operating point, while points (7)-(1) are the operating points obtained by calculations in case of varied rotational speeds.

**[0054]** The curve $\gamma_8$ indicates the flow rate-power consumption characteristics of the pump identified by the first identifying means. The curve $\gamma_8$ includes a plurality of points which are not shown. The coordinates of these points are defined by flow rate and power consumption, as in $(q_1, w_1)$, $(q_2, w_2)$, ....

**[0055]** The processing means establishes a rotational speed ratio for these points as described above. If the rotational speed ratio is 0.95, for example, then $q_1$ is shifted to $q_1 \times 0.95$ and $w_1$ is shifted to $w_1 \times 0.95^3$.

**[0056]** This example assumes that the pump efficiency and the motor efficiency do not change, even when the rotational speed changes. Nor does the example consider heat loss due to frequency conversion when using an inverter. The power consumption may be more accurately calculated by considering these factors.

**[0057]** As described above, this process generates the points $(0.95q_1, 0.95^3 w_1)$, $(0.95q_2, 0.95^3w_2)$, .... The curve $\gamma_7$ is the line connecting these points. This process is repeated for rotational speed ratios of 0.90, 0.85, 0.80, ... to form curves $\gamma_6$-$\gamma_1$. The power consumption corresponding to the operating points of (8)-(1) are indicated by points on the curves $\gamma_8$-$\gamma_1$.

**[0058]** The triangle with diagonal lines in FIG. 12 indicates the design point of the equipment. Hence, when a flow rate of 3500 l/min is required, then the piping resistance that includes actual head is determined to be 38.5 meters according to calculations. However, the point (8) is the actual operating point.

**[0059]** The discrepancy between the design point and the actual operating point is generated by the factors described above (refer to the prior art section). In this example, the flow rate during actual operations exceeds the flow rate at the design point by 40 percent.

**[0060]** The processing means displays the proper rotational speed of the pump for the flow rate at the design point and the power consumption at that rotational speed (operating point). In this example, point (4) is the proper operating point. A comparison of the proper operating point (4) and the actual operating point (8) is shown in Table 1 below.

Table 1

| Item \ Operating point | Actual operating point (8) | Proper operating point (4) |
|---|---|---|
| Flow rate | 4900 l/min | 3500 l/min |
| Head | 27.5 m | 21 m |
| Rotational speed ratio | 1.0 | 0.8 |
| Power consumption | 38 kW | 19 kW |

[0061] As seen in the table, a 50 percent reduction in power consumption can be obtained.

[0062] In the example described above, the flow rate at the design point is defined as the proper operating point. However, this is not always true. It is actually more common to set the flow rate at the design point slightly larger than the required flow rate in order to provide some margin. In this case, it is possible to further lower the rotational speed and further reduce power consumption. Hence, by performing operations at the "true" requirements, an energy-saving can be achieved.

[0063] Establishing provisional values for the actual head, as shown in FIG. 11, would generate three curves β shown in FIG. 12. In this case, it is possible to either identify one curve β by further narrowing the conditions and output one diagnostic result by comparing this curve to the design point of the equipment, or output 3 diagnostic results based on comparing each curve β to the design point of the equipment.

[0064] FIG. 13 is a flow chart showing an outline of the process flow performed in a diagnostic system for fluid machinery shown in FIGS. 1 through 12 and described above in detail.

[0065] In step 1, data (the port diameter of the pump, rating output of the motor, and the like) for identifying the characteristics of the fluid machinery which is to be diagnosed and is actually in operation is inputted into the input device 5.

[0066] In step 2, data (measured values such as the operating pressure, operating flow rate, or the like) for identifying the operating point of the fluid machinery which is actually in operation is inputted into the input device 5.

[0067] In step 3, data (the actual head or the like) for identifying the resistance characteristics on the facility side is inputted into the input device 5.

[0068] In step 4, the transition of the operating point for the fluid machinery caused by a change in the rotational speed of the fluid machinery is calculated by the arithmetic unit 4 and displayed on the output device 6.

[0069] In this manner, according to the present invention, the amount of wasteful energy consumed in the pump or its peripheral devices can be found without the need for bringing an inverter or the like to the work site. Accordingly, it is possible to clarify the return of investment or cost-effectiveness when introducing an inverter or the like, and therefore to help popularize energy saving systems on the market.

[0070] As a means for eliminating wasteful energy found in the method described above, the present invention proposes a controller having a frequency converter as its main component. The applicant of the present invention proposes a performance regulating apparatus for the fluid machinery for use in combination with the present invention as an optimal controller.

[0071] A suitable performance regulating apparatus for fluid machinery for use in combination with the present invention will be able to adjust or regulate the performance of a pump easily in order to save energy. Specifically, the performance regulating apparatus enables the performance of the pump to be adjusted simply by adding an inverter and essentially without changing the existing pump and control panel.

[0072] Next, the performance regulating apparatus for fluid machinery will be described.

[0073] FIG. 14 shows a mounting configuration of a performance regulating apparatus for fluid machinery according to a first embodiment of the present invention. A pump unit 101 comprises a pump 103 and a motor 104 mounted on a common base 102. Fluid introduced through a suction pipe 105 passes through a suction-side gate valve 106 and

a short pipe 107 and is sucked into the pump 103 via a suction port 103a. After the pressure of the fluid is increased in the pump 103, the fluid is discharged from a discharge port 103b. The discharged fluid is introduced into the discharge pipe 110 through a check valve 108 and a discharge-side gate valve 109.

[0074] A performance regulating apparatus 111 for fluid machinery (hereinafter referred to as regulating apparatus) is mounted on the short pipe 107 through a heat radiating means 112. The heat radiating means 112 is composed of an aluminum alloy having good thermal conductivity. In the present embodiment, the heat radiating means 112 is fixed to the regulating apparatus 111 by bolts (not shown), and also fixed to the short pipe 107 via U-bolts (not shown).

[0075] Electric power supplied from a control panel 113 is supplied from an input cable 114 as an input means of the regulating apparatus 111 to a frequency converter housed in the regulating apparatus 111, which converts the frequency of the supplied electric power. The electric power whose frequency has been converted is supplied from an output cable 115 as an output means of the regulating apparatus 111 to the electric motor 104. Although heat loss occurs in the regulating apparatus 111 due to the frequency conversion, in the present embodiment, the generated heat is transferred to the fluid handled by the pump via the heat radiating means 112 and the short pipe 107.

[0076] FIG. 15 shows a mounting configuration of a regulating apparatus according to a second embodiment of the present invention. A pump unit 101 comprises a pump 103 and a motor 104 mounted on a common base 102. Fluid introduced through a suction pipe 105 passes through a suction-side gate valve 106 and a short pipe 107 and is sucked into the pump 103 via a suction port 103a. After the pressure of the fluid is increased in the pump 103, the fluid is discharged from a discharge port 103b. The discharged fluid is introduced into the discharge pipe 110 through a check valve 108 and a discharge-side gate valve 109.

[0077] Electric power supplied from a control panel 113 is supplied from an input cable 114 as an input means of the regulating apparatus 111 to a frequency converter housed in the regulating apparatus 111, which converts the frequency of the supplied electric power. The electric power whose frequency has been converted is supplied from an output cable 115 as an output means of the regulating apparatus 111 to the electric motor 104.

[0078] In the embodiment shown in FIG. 15, a heat radiating means 112 is composed of a water-cooled jacket of stainless steel, and is fixed to the regulating apparatus 111 by bolts (not shown) and to a flange bolt on the short pipe 107 via an L-shaped mounting bracket 116. The fluid discharged from the pump is introduced into the heat radiating means 112 via a small pipe 117, and subsequently bypassed into the suction side of the pump via a small pipe 118.

[0079] In the present embodiment, heat generated during frequency conversion is radiated through the heat radiating means 112, the small pipe 117, and the small pipe 118 into the fluid handled by the pump.

[0080] In the present embodiment, as shown in FIG. 15, a thermal insulation is provided in the area indicated by a dotted line 119. This thermal insulation prevents heat from being transferred from the surface of the pipes to the atmosphere during cooling water circulation and the like. In this case, it is difficult to employ the mounting configuration of the first embodiment shown in FIG. 14, but the mounting configuration of the present embodiment is effective.

[0081] FIGS. 16A and 16B are views showing a detailed structure of the regulating apparatus shown in FIG. 14, and FIG. 16A is a plan view with partially cross-sectional part and FIG. 16B is a side view.

[0082] A heat radiating means 112 is fixed to the short pipe 107 by U-bolts 120. The input cable 114 and the output cable 115 ensure an airtightness with the regulating apparatus 111 by a method similar to underwater cables used in submerged motor pumps, for example. An O-ring 121 is provided to prevent external air from being introduced into the apparatus through the contact surfaces of the heat radiating means 112 and the regulating apparatus 111.

[0083] Next, the peripheral construction of the regulating apparatus 111 will be described with reference to FIG. 17 which is a cross-sectional view taken along line XVII-XVII of FIG. 16A. A frequency converter 48 is housed in a case comprising a base 46 and a cover 47. The base 46 and the cover 47 are fixed together through a seal member 58 by bolts (not shown) to thereby keep an airtightness against external atmosphere.

[0084] The frequency converter 48 is fixed closely to the base 46 in order to transfer generated heat to the base 46. In the same manner, the base 46 and the heat radiating means 112, and the heat radiating means 112 and the short pipe 107 are closely fixed to each other, respectively. As a result, heat generated in the frequency converter is transferred efficiently to the fluid handled by the pump, thereby eliminating the need of a cooling fan or the like used in general-purpose inverters. Hence, there is no fear of poor cooling caused by a fan failure. The heat radiating means 112 is fastened to the base 46 by bolts 55. Further, since the inside of the case is cut off from external atmosphere, the frequency converter is not likely to suffer from insulation deterioration caused by weather or dew condensation.

[0085] FIGS. 18A and 18B are views showing a detailed structure of the regulating apparatus shown in FIG. 15, and FIG. 18A is a front view with partially cross-sectional part and FIG. 18B is a plan view. A heat radiating means 112 is composed of a water-cooled jacket of stainless steel and is provided with a fluid inlet/outlet 122. The input cable, the output cable, and the O-ring 121 have the same structure as those in the example of FIG. 16.

[0086] Next, the peripheral construction of the regulating apparatus 111 will be described with reference to FIG. 19 which is a cross-sectional view taken along line XIX-XIX of FIG. 18A. A frequency converter 48 is housed in a case comprising a base 46 and a cover 47. The base 46 and the cover 47 are fixed together through a seal member 58 by bolts (not shown) to thereby keep an airtightness against external atmosphere.

[0087] The frequency converter 48 is fixed closely to the base 46 in order to transfer generated heat to the base 46. In the same manner, the base 46 is closely fixed to the heat radiating means 112. As a result, heat generated in the frequency converter is transferred efficiently to the fluid handled by the pump, thereby eliminating the need of a cooling fan or the like used in general-purpose inverters.

[0088] Ribs 123 have three roles. The first role is to enhance the strength and rigidity of the heat radiating means 112 in order that the water-cooled jacket is not deformed by the pressure of the fluid. The second role is to guide the flow of fluid within the jacket in order to preserve its holding time therein. The third role is to improve the radiating effect by increasing the area of contact with the fluid. According to the present embodiment, the apparatus can be easily and effectively cooled, even if a thermal insulation is provided around the piping.

[0089] Next, a third embodiment of the present invention will be described with reference to FIGS. 20A and 20B. The basic structure of the apparatus in the third embodiment is the same as that in the first and second embodiments. However, the regulating apparatus 111 of the third embodiment is an air-cooled type that includes a coupling 126 joining the pump 103 and the motor 104 and utilizes the air flow generated by the rotation of the coupling 126.

[0090] As shown in FIG. 20B (view as viewed from an arrow XX of FIG. 20A), a coupling guard is disposed around the coupling 126 for preventing accidents. In the present embodiment, the coupling guard serves as a heat radiating means 112.

[0091] Here, the coupling guard (heat radiating means) 112 is composed of an aluminum alloy and provided with a plurality of cooling ribs (fins) 128 for improving the cooling effect of the air flow described above. The structure of the case is the same as that in the first and second embodiments, and the case can withstand wind and rain.

[0092] Next, the embodiment shown in FIGS. 21A and 21B will be described. FIGS. 21A and 21B show another embodiment of the apparatuses shown in FIGS. 14 through 20, and FIG. 21A is a front view and FIG. 21B is a side view. In brief, the present embodiment is different from other embodiments in that the output cable 115 is provided on the base 46.

[0093] This construction is even simpler, because there is no need to mount the output cable 115 on the heat radiating means 112. Further, it is obvious that this construction can be applied both to the water-cooled jacket type and the air-cooled type.

[0094] In FIGS. 16A, 16B, 18A, 21A, and 21B, a screw cap 124 is provided for ensuring an airtightness against external atmosphere via an O-ring (not shown) interposed therebetween. An adjusting means for adjusting output frequency is provided inside the screw cap 124. For example, the adjusting means comprises a rotary step switch for appropriately adjusting the rotational speed of the fluid machinery.

[0095] As is intentionally not shown in the drawings, in the present invention, there is no component corresponding to a switch for turning output from the frequency converter on and off. Thus, the frequency converter is constructed to provide output automatically when electric power is supplied thereto. Accordingly, there is no restriction on a position where the apparatus is attached to the pipe. For example, the apparatus can be mounted at a position out of reach from children or in a small space, because the fluid machinery starts and stops simply by turning the power on and off.

[0096] By incorporating the performance regulating apparatus (hereinafter referred to as controller) for fluid machinery shown in FIGS. 14 through 21B in the system of the present invention, it is possible to find the amount of wasteful energy in the fluid machinery with good accuracy. This controller can set the output frequency to eight different settings at a 5 percent step. Since these steps correspond to the rotational speed ratio of the processing means described above, it is possible to verify the actual power consumption while operating the system. In the processing means described above, heat loss by the inverter was ignored. However, an accurate value for power consumption can be calculated as measured data by actually driving the apparatus with the inverter.

[0097] This controller serves as not only a means for estimating the amount of wasteful energy but also an extremely effective means for eliminating the estimated wasteful energy. This is because the controller can withstand use in the outdoors, which is a common installation site for pumps. The controller is not required to be housed in a control panel, and hence any special alteration or construction expenses are not required. The controller can be taken to the site, installed, and tested to determine whether it is cost-effective. Then, if it is cost-effective, the controller may be left installed.

[0098] By using this controller, the actual head can be found with great accuracy. As shown in FIG. 22, the operating pressure (head) when the valve (gate valve) is open is compared to the operating pressure when the valve is closed, while varying the rotational speed of the pump, and the actual head is found at the point where there is no difference between the two operating pressures. As shown in Table 2, the actual head in this example is 19 meters.

Table 2

| No. | | (8) | (7) | (6) | (5) | (4) | (3) | (2) | (1) | |
|---|---|---|---|---|---|---|---|---|---|---|
| Rotational speed ratio | | 1.0 | 0.95 | 0.90 | 0.85 | 0.80 | 0.75 | 0.71 | 0.67 | |
| Head (m) | Valve closed | 41.5 | 37.5 | 33.5 | 30 | 26 | 23 | 21 | 19 | Actual head: 19 m |
| | Valve open | 32 | 29.5 | 27.5 | 25.5 | 23.5 | 22 | 20 | 19 | |

[0099] Accordingly, the actual head can be easily found using the controller of the present invention, even in the case where the actual head is difficult to be found (for example, with a complex piping system). By inputting this value into the input device 5 and executing the processing means, the accuracy of the system is further improved.

[0100] The first identifying means, the second identifying means, and the processing means described above are implemented as programs for operating a computer and stored on a storage medium. This storage medium can be incorporated into a notebook type personal computer or the like, which can be easily carried to the site of the pump installation.

[0101] FIG. 23 shows an example of equipment that can be carried to the operating site of the fluid machinery to be diagnosed. This equipment includes a personal computer PC comprising a main controller 1 (having a control unit 3 and an arithmetic unit 4), a main storage unit 2, an input device 5, and an LCD forming part of an output device 6, all of which are shown in FIG. 1; a floppy disk (FD) or CD-ROM serving as the storage medium for storing the above programs; and a printer PR forming another part of the output device 6. The equipment further includes a compound pressure gauge $C_{PG}$ attached to the suction side of the fluid machinery such as a pump; a pressure gauge $P_G$ attached to the discharge side; and a power meter $P_W$ for measuring power consumption of the motor for driving the fluid machinery.

[0102] As described above, the present invention can find the amount of wasteful energy consumption in the fluid machinery and its peripheral devices. Specifically, the amount of wasteful energy consumed in the fluid machinery and its peripheral devices can be estimated without installing an inverter on the site. Accordingly, the return of investment of introducing an inverter or the like can be found to help popularize energy conserving equipment on the market.

[0103] The controller (performance regulating apparatus) of the present invention makes it possible to identify and eliminate wasteful energy. Since the controller of the present invention has the effect of decreasing the rotational speed of the fluid machinery, it can be expected to extend the life of the bearings, mechanical seals, and the like.

[0104] The present invention can perform its energy saving diagnosis without shutting off the pump, changing the opening degree of the valve, or causing some other hindrance to the user's equipment. In other words, the diagnosis can be executed during equipment operations, on a workday rather than a holiday.

[0105] The present invention is also suitable when an energy saving diagnosis of greater accuracy is required. This procedure, however, requires that the equipment is shut down or data is gathered in case of changing the opening degree of the valve.

[0106] The present invention can be applied in various situations to perform appropriate measures as required by the circumstances, such as adding a controller or converting the fluid machinery to a small fluid machinery having a one rank smaller capacity.

[0107] Further, since the loss in the piping side (facility side) can be found, it is possible to perform a simple trial calculation of energy conservation achieved by increasing the piping diameter by one rank.

[0108] Next, a method for identifying characteristics of fluid machinery according to the present invention will be described based on the example of a centrifugal pump. The following method employs the first and second identifying means of the embodiments shown in FIGS. 1 through 13.

[0109] Generally, models of centrifugal pumps are designed so as to cope with port diameters, motor output and rotational speed. The range of flow rate is approximately determined by the port diameter and the rated rotational speed of the motor, and the head is approximately determined by the motor output. Therefore, the specific speed $N_S$ of the centrifugal pump can be estimated from its port diameter, the number of impeller stages, and the motor output and rotational speed. Here, the specific speed $N_S$ is defined by the following expression and used at the design stage.

$$N_S = NQ^{1/2} / H^{3/4}$$

Here, N denotes the rotational speed, Q the flow rate, and H the head at a single impeller stage.

[0110] Characteristics of the pump including the flow rate-head characteristics and flow rate-shaft power characteristics vary according to specific speed. The pump efficiency also varies according to specific speed. The above pump characteristics (the flow rate-head characteristics and flow rate-shaft power characteristics) can be depicted for specific speeds as dimensionless characteristics of the pump, shown in FIG. 24. The pump efficiency can be arranged as specific speed-pump efficiency characteristics, shown in FIG. 25. In FIG. 24, the horizontal axis represents dimensionless flow rate (Q), while the vertical axis represents both dimensionless head (H) and dimensionless shaft power (kW). The characteristics of the pump are indicated for specific speeds ($N_S$) of 560, 400, 280, ..., 50. In FIG. 25, the horizontal axis represents specific speed ($N_S$), while the vertical axis represents pump efficiency $\eta$ (%).

[0111] Hence, by setting representative points (flow rate, head, and shaft power having dimensions) in FIG. 24, it is possible to estimate the overall pump characteristics as provisional characteristics.

[0112] Once the provisional characteristics of the pump have been estimated, the characteristics of the fluid machinery can be identified by correcting the provisional characteristics so that they match the pump operating point (flow rate) and measured data (head and power consumption) during pump operations. Data for FIGS. 24 and 25 is prepared in a database.

[0113] Next, the stages of estimating provisional pump characteristics, identifying the operating point (flow rate), and correcting the provisional characteristics are described with reference to FIGS. 26A through 26D. Here, the provisional characteristics are corrected using flow rate calculated from the head and power consumption during current operations and estimated values of the efficiency of the fluid machinery and the efficiency of the motor.

[0114] In the step shown in FIG. 26A, data is inputted into the input device 5 shown in FIG. 1. This data includes the pump type data including the port diameter (Ø) and the number of stages (STG); the motor data including rated output ($P_0$) and rated rotational speed (N); and measured data including the head (H) and power consumption (Pi) during current operations.

[0115] Next, the main controller 1 shown in FIG. 1 performs the following five steps to create the provisional pump characteristics shown in FIG. 26B. In step 1, the specific speed ($N_S$) is identified by the pump port diameter (Ø) and the number of stages (STG), the rated output ($P_0$) of the motor and the rated rotational speed (N) of the motor. In step 2, the flow rate at the best efficiency point ($Q_{BEP}$) is identified by the pump port diameter (Ø) and the number of stages (STG), the rated rotational speed (N) of the motor, and the specific speed ($N_S$). Here, $Q_{BEP}$ is defined as flow rate at the best efficiency point. In step 3, the pump efficiency ($\eta_P$) is identified by the pump port diameter (Ø) and the number of stages (STG) and the specific speed ($N_S$). In step 4, the head at the best efficiency point ($H_{BEP}$) is calculated according to the expression $H_{BEP} = \eta_P \cdot P_0/0.163 \cdot \gamma \cdot Q_{BEP}$. Here, $H_{BEP}$ is defined as pump heat at the best efficiency point, and $\gamma$ is the specific weight of the fluid. In step 5, provisional pump characteristics as shown by the dotted lines in FIG. 26B are created using the dimensionless characteristics of the pump shown in FIG. 24 based on the identified specific speed and representative point [($Q_{BEP}$, $H_{BEP}$) and ($Q_{BEP}$, $P_0$)]. That is, a flow rate-head characteristic curve corresponding to the specific speed ($N_S$) identified in step 1 is selected from FIG. 24. Then, a provisional flow rate-head characteristic curve is created by depicting the selected flow rate-head characteristic curve such that the point (1.0, 1.0) in FIG. 24 overlaps the point ($Q_{BEP}$, $H_{BEP}$) in FIG. 26B. Further, a flow rate-shaft power characteristic curve corresponding to the specific speed ($N_S$) identified in step 1 is selected from FIG. 24. Then, a provisional flow rate-shaft power characteristic curve is created by depicting the selected flow rate-shaft power characteristic curve such that the point (1.0, 1.0) in FIG. 24 overlaps the point ($Q_{BEP}$, $P_0$) in FIG. 26B. Data for steps 1-3 is prepared in a database.

[0116] Next, the flow rate identification shown in FIG. 26C is performed according to the following two steps. In step 1, the motor efficiency ($\eta_M$) is identified by the rated output ($P_0$) of the motor. In this case, the data is stored in a database in order that the motor efficiency ($\eta_M$) can be identified by inputting the rated output ($P_0$) of the motor. In step 2, the current flow rate (Q) is calculated according to the expression $Q = \eta_M \cdot \eta_P \cdot Pi/0.163 \cdot \gamma \cdot H$. Since the current flow rate (Q) and the motor efficiency ($\eta_M$) are identified in steps 1 and 2 and the current head (H) is known, the identified operating point can be illustrated in a graph of flow rate-head shown in FIG. 26C. Further, the identified operating point can be illustrated in a graph of flow rate-shaft power by calculating $Pi \cdot \eta_M$.

[0117] Next, the following two steps are performed to identify pump characteristics by correcting provisional pump characteristics, as shown in FIG. 26D. The dotted line in FIG. 26D denotes the provisional pump characteristics, while the solid line indicates the corrected pump characteristics. In step 1, the provisional head characteristics are corrected by the ratio $H_A/H_B$. In step 2, the provisional shaft power characteristics are corrected by the ratio $P_A/P_B$. Here, $H_A$ and $P_A$ are the head and the shaft power at the operating point specified in FIG. 26C. $H_B$ and $P_B$ are the head and the shaft power on the provisional pump characteristic curve at the current flow rate (Q).

[0118] Next, the stages of estimating provisional pump characteristics, identifying the operating point (flow rate), and correcting the provisional characteristics are described with reference to FIGS. 27A through 27D. Here, the provisional characteristics are corrected using flow rate calculated from the head and the power consumption during current operations and estimated values of the efficiency of the fluid machinery and the efficiency of the motor, and the head and the power consumption during shutoff operations.

[0119] In the step shown in FIG. 27A, data is inputted into the input device 5 shown in FIG. 1. This data includes the pump type data including the port diameter (Ø) and the number of stages (STG); the motor data including rated output ($P_0$) and rated rotational speed (N); and measured data including the head (H) and power consumption (Pi) during current operations, and the head ($H_S$) and power consumption (Pis) during shutoff operations.

[0120] Next, the main controller 1 shown in FIG. 1 performs the following three steps to create the provisional pump characteristics shown in FIG. 27B. In step 1, the specific speed ($N_S$) is identified by the pump port diameter (Ø) and the number of stages (STG), the rated output ($P_0$) of the motor and the rated rotational speed (N) of the motor. In step 2, the flow rate at the best efficiency point ($Q_{BEP}$) is identified by the pump port diameter (Ø) and the number of stages (STG), the rated rotational speed (N) of the motor, and the specific speed ($N_S$). In step 3, provisional pump characteristics as shown in FIG. 27B are created by setting $Q_{BEP}$ as the representative point in the X direction and head ($H_S$) and power consumption (Pis) during shutoff operations as the representative point in the Y direction. Here, the provisional pump characteristics are created using the dimensionless characteristics of the pump shown in FIG. 24, as described in the embodiment shown in FIGS. 26A through 26D. Data for steps 1 and 2 is prepared in a database.

[0121] Next, the flow rate identification shown in FIG. 27C is performed according to the following two steps. In step 1, the motor efficiency ($\eta_M$) is identified by the rated output ($P_0$) of the motor. In this case, the data is stored in a database in order that the motor efficiency ($\eta_M$) can be identified by inputting the rated output ($P_0$) of the motor. In step 2, the current flow rate (Q) is calculated according to the expression $Q = \eta_M \cdot \eta_P \cdot Pi/0.163 \cdot \gamma \cdot H$. Since the current flow rate (Q) and the motor efficiency ($\eta_M$) are identified in steps 1 and 2 and the current head (H) is known, the identified operating point can be illustrated in a graph of flow rate-head shown in FIG. 27C. Further, the identified operating point can be illustrated in a graph of flow rate-shaft power by calculating $Pi \cdot \eta_M$.

[0122] Next, the following two steps are performed to identify pump characteristics by correcting provisional pump characteristics, as shown in FIG. 27D. The dotted line in FIG. 27D denotes the provisional pump characteristics, while the solid line indicates the corrected pump characteristics. In step 1, the provisional flow characteristics are corrected by the ratio $Q/Q_B$. In step 2, the shaft power curve is corrected to approximate a curve through points (0, $Pis \cdot \eta_M$) and (Q, $Pi \cdot \eta_M$).

[0123] Next, the stages of estimating provisional pump characteristics, identifying the operating point (flow rate), and correcting the provisional characteristics are described with reference to FIGS. 28A through 28D. Here, the provisional characteristics are corrected using flow rate calculated from the head and the power consumption during current operations and estimated values of the efficiency of the fluid machinery and the efficiency of the motor, and the head and the power consumption during operations when the valve is fully open.

[0124] In the step shown in FIG. 28A, data is inputted into the input device 5 shown in FIG. 1. This data includes the pump type data including the port diameter (Ø) and the number of stages (STG); the motor data including rated output ($P_0$) and rated rotational speed (N); and measured data including the head (H) and the power consumption (Pi) during current operations, and the head ($H_V$) and the power consumption (Piv) during operations when the valve is fully open.

[0125] Next, the main controller 1 shown in FIG. 1 performs the following five steps to create the provisional pump characteristics shown in FIG. 28B. In step 1, the specific speed ($N_S$) is identified by the pump port diameter (Ø) and the number of stages (STG), the rated output ($P_0$) of the motor and the rated rotational speed (N) of the motor. In step 2, the flow rate at the best efficiency point ($Q_{BEP}$) is identified by the pump port diameter (Ø) and the number of stages (STG), the rated rotational speed (N) of the motor, and the specific speed ($N_S$). In step 3, the pump efficiency ($\eta_P$) is identified by the pump port diameter (Ø) and the number of stages (STG) and the specific speed ($N_S$). In step 4, the head at the best efficiency point ($H_{BEP}$) is calculated according to the expression $H_{BEP} = \eta_P \cdot P_0/0.163 \cdot \gamma \cdot Q_{BEP}$. In step 5, provisional pump characteristics as shown by the dotted lines in FIG. 28B are created based on the identified specific speed and representative point [($Q_{BEP}$, $H_{BEP}$) and ($Q_{BEP}$, $P_0$)]. Here, the provisional pump characteristics are created using the dimensionless characteristics of the pump shown in FIG. 24, as described in the embodiment shown in FIGS. 26A through 26D. Data for steps 1-3 is prepared in a database.

[0126] Next, the flow rate identification shown in FIG. 28C is performed according to the following two steps. In step 1, the motor efficiency ($\eta_M$) is identified by the rated output ($P_0$) of the motor. In this case, the data is stored in a database in order that the motor efficiency ($\eta_M$) can be identified by inputting the rated output ($P_0$) of the motor. In step 2, the current flow rate (Q) is calculated according to the expression $Q = \eta_M \cdot \eta_P \cdot Pi/0.163 \cdot \gamma \cdot H$. Since the current flow rate (Q) and the motor efficiency ($\eta_M$) are identified in steps 1 and 2 and the current head (H) is known, the identified operating point can be illustrated in a graph of flow rate-head shown in FIG. 28C. Further, the identified operating point can be illustrated in a graph of flow rate-shaft power by calculating $Pi \cdot \eta_M$.

[0127] Next, the following five steps are performed to identify pump characteristics by correcting provisional pump characteristics, as shown in FIG. 28D. The dotted line in FIG. 28D denotes the provisional pump characteristics, while the solid line indicates the corrected pump characteristics. In step 1, the provisional head characteristics are corrected by the ratio $H_A/H_B$. In step 2, the provisional shaft power characteristics are corrected by the ratio $P_A/P_B$. Here, $H_A$ and $P_A$ are the head and the shaft power at the operating point specified in FIG. 28C. $H_B$ and $P_B$ are the head and the shaft

power on the provisional pump characteristic curve at the current flow rate (Q). In step 3, the flow rate ($Q_V$) during operations when the valve is fully open is identified from the head ($H_V$) during operations when the valve is fully open. In step 4, the shaft power ($Piv \cdot \eta_M$) during $Q_V$ is identified. In step 5, the shaft power curve is corrected to approximate a curve through points (Q, $Pi \cdot \eta_M$) and ($Q_V$, $Piv \cdot \eta_M$).

**[0128]** Next, the stages of estimating provisional pump characteristics, identifying the operating point (flow rate), and correcting the provisional characteristics are described with reference to FIGS. 29A through 29D. Here, the provisional characteristics are corrected using flow rate calculated from the head and the power consumption during current operations and estimated values of the efficiency of the fluid machinery and the efficiency of the motor, and the head and the power consumption during both shutoff operations and operations when the valve is fully open.

**[0129]** In the step shown in FIG. 29A, data is inputted, into the input device 5 shown in FIG. 1. This data includes the pump type data including the port diameter (Ø) and the number of stages (STG); the motor data including rated output ($P_0$) and rated rotational speed (N); and measured data including the head (H) and the power consumption (Pi) during current operations, the head ($H_S$) and the power consumption (Pis) during shutoff operations, and the head ($H_V$) and the power consumption (Piv) during operations when the valve is fully open.

**[0130]** Next, the main controller 1 shown in FIG. 1 performs the following three steps to create the provisional pump characteristics shown in FIG. 29B. In step 1, the specific speed ($N_S$) is identified by the pump port diameter (Ø) and the number of stages (STG), the rated output ($P_0$) of the motor and the rated rotational speed (N) of the motor. In step 2, the flow rate at the best efficiency point ($Q_{BEP}$) is identified by the pump port diameter (Ø) and the number of stages (STG), the rated rotational speed (N) of the motor, and the specific speed ($N_S$). In step 3, provisional pump characteristics as shown in FIG. 29B are created by setting $Q_{BEP}$ as the representative point in the X direction and the head ($H_S$) and the power consumption (Pis) during shutoff operations as the representative point in the Y direction. Here, the provisional pump characteristics are created using the dimensionless characteristics of the pump shown in FIG. 24, as described in the embodiment shown in FIGS. 26A through 26D. Data for steps 1 and 2 is prepared in a database.

**[0131]** Next, the flow rate identification shown in FIG. 29C is performed according to the following two steps. In step 1, the motor efficiency ($\eta_M$) is identified by the rated output ($P_0$) of the motor. In this case, the data is stored in a database in order that the motor efficiency ($\eta_M$) can be identified by inputting the rated output ($P_0$) of the motor. In step 2, the current flow rate (Q) is calculated according to the expression $Q = \eta_M \cdot \eta_P \cdot Pi/0.163 \cdot \gamma \cdot H$. Since the current flow rate (Q) and the motor efficiency ($\eta_M$) are identified in steps 1 and 2 and the current head (H) is known, the identified operating point can be illustrated in a graph of flow rate-head shown in FIG. 29C. Further, the identified operating point can be illustrated in a graph of flow rate-shaft power by calculating $Pi \cdot \eta_M$.

**[0132]** Next, the following two steps are performed to identify pump characteristics by correcting provisional pump characteristics, as shown in FIG. 29D. The dotted line in FIG. 29D denotes the provisional pump characteristics, while the solid line indicates the corrected pump characteristics. In step 1, the provisional flow characteristics are corrected by the ratio $Q/Q_B$. In step 2, the shaft power curve is corrected to approximate a curve through points (0, $Pis \cdot \eta_M$), (Q, $Pi \cdot \eta_M$), and ($Q_V$, $Piv \cdot \eta_M$).

**[0133]** Next, the stages of estimating provisional pump characteristics, identifying the operating point (flow rate), and correcting the provisional characteristics are described with reference to FIGS. 30A through 30D. Here, the operating point (flow rate) is identified from the provisional characteristics and the head during current operations, while the provisional characteristics are corrected according to the current power consumption.

**[0134]** In the step shown in FIG. 30A, data is inputted into the input device 5 shown in FIG. 1. This data includes the pump type data including the port diameter (Ø), the number of stages (STG), a first element (Q1, H1), and a second element (Q2, H2); the motor data including rated output ($P_0$) and rated rotational speed (N); and measured data including the head (H) and the power consumption (Pi) during current operations.

**[0135]** Next, the main controller 1 shown in FIG. 1 performs the following five steps to create the provisional pump characteristics shown in FIG. 30B. In step 1, the specific speed ($N_S$) is identified by the pump port diameter (Ø) and the number of stages (STG), the rated output ($P_0$) of the motor and the rated rotational speed (N) of the motor. In step 2, the shutoff head ($H_S$') is assumed based on the equation $H_S' = (H1 + 2 \times H2)/3$. In step 3, a head curve is created so as to pass through the points (0, $H_S$') and (Q2, H2), as indicated by the dotted line, and a shaft power curve is created so as to pass through the point ($Q_{MAX}$, $P_0$), as indicated by the dotted line, based on the identified specific speed ($N_S$). Here, the provisional pump characteristics are created using the dimensionless characteristics of the pump shown in FIG. 24. In step 4, the point (Q2, H2) is set as the point of origin, and the head curve indicated by a solid line is created by correcting the head at a ratio $\Delta H/(H1 - H2)$. In step 5, the shaft power curve indicated by the two-dot chain line is created by applying the corrected value for the head curve having its origin at (0, 0) to the shaft power curve. Data for step 1 is prepared in a database.

**[0136]** Next, the flow rate identification shown in FIG. 30C is performed according to the following two steps. In step 1, the motor efficiency ($\eta_M$) is identified by the rated output ($P_0$) of the motor. In step 2, the current operating flow rate (Q) is identified by the head (H) during current operations. In addition, the current shaft power ($Pi \cdot \eta_M$) is identified by calculating $Pi \cdot \eta_M$. Data for step 1 is prepared in a database.

**[0137]** Next, the following step is performed to identify pump characteristics by correcting provisional pump characteristics, as shown in FIG. 30D. In this step, the shaft power curve indicated by a solid line is created by correcting the shaft power curve at the ratio $(Pi \cdot \eta_M)/P_A$.

**[0138]** Next, the stages of estimating provisional pump characteristics, identifying the operating point (flow rate), and correcting the provisional characteristics are described with reference to FIGS. 31A through 31D. Here, the operating point (flow rate) is identified from the provisional characteristics and the head during current operations, while the provisional characteristics are corrected according to the current power consumption and the head and the power consumption when the valve is fully open.

**[0139]** In the step shown in FIG. 31A, data is inputted into the input device 5 shown in FIG. 1. This data includes the pump type data including the port diameter (∅), the number of stages (STG), a first element (Q1, H1), and a second element (Q2, H2): the motor data including rated output ($P_0$) and rated rotational speed (N); and measured data including the head (H) and power consumption (Pi) during current operations, and the head ($H_V$) and the power consumption (Piv) during operations when the valve is fully open.

**[0140]** Next, the main controller 1 shown in FIG. 1 performs the following five steps to create the provisional pump characteristics shown in FIG. 31B. In step 1, the specific speed ($N_S$) is identified by the pump port diameter (∅) and the number of stages (STG), the rated output ($P_0$) of the motor and the rated rotational speed (N) of the motor. In step 2, the shutoff head ($H_S$') is assumed based on the equation $H_S' = (H1 + 2 \times H2)/3$. In step 3, a head curve is created so as to pass through the points (0, $H_S$') and ($Q_2$, $H_2$), as indicated by the dotted line, and a shaft power curve is created so as to pass through the point ($Q_{MAX}$, $P_0$), as indicated by the dotted line, based on the identified specific speed ($N_S$). Here, the provisional pump characteristics are created using the dimensionless characteristics of the pump shown in FIG. 24. In step 4, the point (Q2, H2) is set as the point of origin, and the head curve indicated by a solid line is created by correcting the head at a ratio $\Delta H/(H1 - H2)$. In step 5, the shaft power curve indicated by the two-dot chain line is created by applying the corrected value for the head curve having its origin at (0, 0) to the shaft power curve. Data for step 1 is prepared in a database.

**[0141]** Next, the flow rate identification shown in FIG. 31C is performed according to the following two steps. In step 1, the motor efficiency ($\eta_M$) is identified by the rated output ($P_0$) of the motor. In step 2, the current operating flow rate (Q) is identified by the head (H) during current operations. In addition, the current shaft power ($Pi \cdot \eta_M$) is identified by calculating $Pi \cdot \eta_M$. Data for step 1 is prepared in a database.

**[0142]** Next, the following three steps are performed to identify pump characteristics by correcting provisional pump characteristics, as shown in FIG. 31D. In step 1, the shaft power curve is corrected by the ratio $(Pi \cdot \eta_M)/P_A$. In step 2, the flow rate ($Q_V$) when the valve is fully open is identified by $H_V$, and the shaft power ($Piv \cdot \eta_M$) when the valve is fully open is identified. In step 3, the shaft power curve is approximated to a curve passing through the points (Q, $Pi \cdot \eta_M$) and ($Q_V$, $Piv \cdot \eta_M$).

**[0143]** As described above, one of the methods shown in FIGS. 26A through 31D is used to estimate provisional pump characteristics, identify the operating point (flow rate), and correct the provisional characteristics in order to identify the pump characteristics. Accordingly, the characteristic curves shown in FIG. 6 can be identified even when pump experimental data cannot be obtained. Therefore, the diagnostic system of the present invention can function at a relatively high precision.

**[0144]** The diagnostic system shown in FIGS. 1 through 31D performs a diagnosis by measuring power consumption and the like at the work site while the pump is performing actual operations. Hence, although the diagnostic precision may be high, gathering data is time-consuming.

**[0145]** Specifically, the diagnostic system shown in FIGS. 1 through 31D requires a so-called main diagnosis in which the system is tested at the work site while the pump is in actual operations. Therefore, the inventors of the present invention have studied a method for learning the return of investment or cost-effectiveness when introducing an inverter, wherein a simple theoretical diagnosis is conducted prior to performing the main diagnosis at the work site. Here, the return of investment or cost-effectiveness is defined as the effect of reducing power consumption by introducing an inverter in relation to the cost of introducing the inverter. By performing this simple pre-diagnosis, it is possible to occasionally omit the main, diagnosis and reduce the cost of the diagnoses.

**[0146]** Next, an energy-saving pre-diagnostic system for saving energy in fluid machinery according to a first embodiment of the present invention will be described with reference to the drawings. The mechanical construction of the energy-saving pre-diagnostic system for fluid machinery according to the present embodiment is similar to the construction shown in FIG. 1. In the present embodiment, the fluid machinery will be described using the example of a pump.

**[0147]** As shown in FIG. 1, the energy-saving pre-diagnostic system for fluid machinery comprises a main controller 1 for controlling the overall system, and a main storage unit 2 connected to the main controller 1. The main controller 1 includes a control unit 3 and an arithmetic unit 4. The main controller 1 is also connected to an input device 5 including a keyboard, mouse, or the like and an output device 6 including a printer, display, or the like.

**[0148]** The main controller 1 has an internal memory (not shown) for storing control programs such as an operating

system, a program prescribing the diagnostic procedure for the fluid machinery, and required data. The main storage unit 2 includes a hard disk, floppy disk, optical disk, or the like and stores data for various models of pumps currently appearing on the market. However, the pump data can also be inputted each time into the input device 5.

[0149] FIG. 32 is a view showing the flow rate-head characteristics and the flow rate-power consumption characteristics of the pump. In FIG. 32, the horizontal axis represents flow rate (l/min), while the vertical axis represents total head (m) or the power consumption (kW).

[0150] The flow rate-head and flow rate-power consumption data for motor pumps driven by a commercial AC power supply is prepared in advance in the form of a general test report or a representative characteristic curve. By inputting approximately 5 points from the results (five points shown by dots in FIG. 32), it is possible to draw the curves $\alpha_8$ and $\gamma_8$ shown in FIG. 32 using an appropriate function.

[0151] The filled-in area of roughly triangular shape shown in the diagram indicates the design specifications of the equipment side. Since it is known that the energy loss in piping is proportional to the square of the flow rate, it is possible to draw a system head curve $\beta$ through the design specifications of the equipment by inputting the actual head (that is, the resistance in the pipeline at zero flow rate).

[0152] If the actual head is not known, the value, for example, 50% of the head in the design specifications can be estimated.

[0153] The present invention comprises a calculating means for calculating the reduced amount of power consumption when using a frequency converter to decrease the rotational speed of the fluid machinery. Next, the function of the calculating means is described with reference to FIG. 33.

[0154] The curve $\alpha_8$ of FIG. 33 includes a plurality of points which are not shown. The coordinates of these points are defined by flow rate and head, as in $(q_1, h_1)$, $(q_2, h_2)$, ....

[0155] The calculating means establishes a rotational speed ratio for these points. If the rotational speed ratio is 0.95, for example, then $q_1$ is shifted to $q_1 \times 0.95$ and $h_1$ is shifted to $h_1 \times 0.95^2$. This generates the points $(0.95q_1, 0.95^2h_1)$, $(0.95q_2, 0.95^2h_2)$, .... The curve $\alpha_7$ is the line connecting these points. This process is repeated for rotational speed ratios of 0.90, 0.85, 0.80, ... to form curves $\alpha_6$-$\alpha_1$.

[0156] The curve $\beta$ is the system head curve on the facility side (piping side) calculated by the above-described method. The point denoted by (8) in the drawing is the actual operating point, while points (7)-(1) are the operating points obtained by calculations with varied rotational speeds. However, the true operating point often has a larger flow rate than necessary, in order to allow some margin in the estimations of design specifications for piping loss.

[0157] The curve $\gamma_8$ includes a plurality of points which are not shown. The coordinates of these points are defined by flow rate and power consumption, as in $(q_1, w_1)$, $(q_2, w_2)$, ....

[0158] The calculating means establishes a rotational speed ratio for these points as described above. If the rotational speed ratio is 0.95, for example, then $q_1$ is shifted to $q_1 \times 0.95$ and $w_1$ is shifted to $w_1 \times 0.95^3$.

[0159] This example assumes that the pump efficiency and the motor efficiency do not change, even when the rotational speed changes. Nor does the example consider heat loss due to frequency conversion when using an inverter. The power consumption can be more accurately calculated by considering these factors.

[0160] As described above, this process generates the points $(0.95q_1, 0.95^3w_1)$, $(0.95q_2, 0.95^3w_2)$, .... The curve $\gamma_7$ is the line connecting these points. This process is repeated for rotational speed ratios of 0.90, 0.85, 0.80, ... to form curves $\gamma_6$-$\gamma_1$.

[0161] The power consumption corresponding to the operating points of (8)-(1) is indicated by points on the curves $\gamma_8$-$\gamma_1$.

[0162] FIG. 34 shows an example of actual output (printout) from the output device 6 for the characteristics described in FIG. 33. That is, FIG. 34 is a view showing a diagnostic result 10 outputted by the output device 6. The two graphs in FIG. 34 show the flow rate-head characteristic curves and the flow rate-power consumption characteristic curves found in FIG. 33. A table at the bottom of FIG. 34 is represented by the letter A. This portion A is enlarged and shown in FIG. 35. This portion A of FIG. 34 is a table showing calculated values of power consumption reductions. The items in the first column of FIG. 35 indicate the flow rate during actual operations for fluid machinery driven by a commercial power source; cases when using an inverter to meet the design flow rate; and cases when using an inverter to reduce the flow rate below the design flow rate.

[0163] Items in the top row of the table include the rotational speed ratio (1.0 when driven by a commercial power source), power consumption, the amount of power consumption (calculated from the work time inputted separately from power consumption), $CO_2$ emissions (calculated using a coefficient indicated in the diagram for the amount of power consumption), reduction of power consumption, reduced power costs (calculated using the unit price 13 yen/kWh), and reduction ratio (electric energy • $CO_2$ • electric power cost).

[0164] In this example, an energy savings of 18% can be achieved simply by matching the flow rate to the design value, amounting to a reduction in energy costs of 286,000 yen/year. If the design flow rate itself has been estimated with some margin, it may be possible to reduce the flow rate by 10%, for example, thereby achieving an energy savings of 40%, and amounting to a reduction in energy costs of 639,600 yen/year. In this manner, it is possible to estimate the

length of time required to recover an investment for installing an inverter.

[0165] The calculating means for calculating how much power consumption can be reduced when using a frequency converter to decrease the rotational speed of the fluid machinery and the processing means for displaying the calculated results, as described above, are implemented as programs for operating a computer and stored on a storage medium. This storage medium can be incorporated into a personal computer or the like.

[0166] FIG. 36 is a schematic view showing an example of an energy-saving pre-diagnostic system for fluid machinery implemented by a personal computer. This system includes a personal computer PC comprising a main controller 1 (having a control unit 3 and an arithmetic unit 4), a main storage unit 2, an input device 5, and an LCD forming part of an output device 6, all of which are shown in FIG. 1; a floppy disk (FD) or CD-ROM serving as the storage medium for storing the above programs; and a printer PR forming another part of the output device 6.

[0167] As described above, the present invention can find in advance the amount of wasteful energy consumption in the fluid machinery and its peripheral devices. With the system of the present invention, it is easy to calculate the amount of energy savings possible using an inverter or the like to adjust the rotational speed, without performing actual operations with the fluid machinery at the work site. Accordingly, the return of investment or cost-effectiveness of introducing an inverter or the like can be found, and this can help popularize energy conserving equipment on the market.

[0168] Next, a method and material for displaying characteristics of the fluid machinery according to an embodiment of the present invention will be described with reference to drawings.

[0169] FIG. 37 shows an example of applying the present invention to a motor-driven centrifugal pump. Here, the motor is a 3-phase induction motor. The outer rectangle 10 describes the periphery of a flat surface 11 comprising a display material, such as space in a catalog. Curves 12 showing the Q-H characteristics, and data 14, 15, and the like relating to power consumption are recorded on the surface 11.

[0170] The curves (Q-H characteristic curves) 12 indicate the Q-H characteristics plotted according to the discharge amount represented by the horizontal axis and the total head represented by the vertical axis. One curve 12 is recorded for each frequency supplied to the motor. There are nine frequencies in this example: An operating frequency 13 for the pump motor is numerically recorded adjacent to each curve 12. These curves 12 can either all be the measured data or can be the calculated values based on the function (1) provided below.

$$Q \propto N \tag{1}$$
$$H \propto N^2$$
$$N \propto F$$
$$W \propto N^3$$

[0171] Here, Q is the discharge amount, H the total head, N the rotational speed, F the frequency, and W the power consumption.

[0172] An approximate power consumption 14 and an approximate annual energy charge 15 are numerically recorded adjacent to the curves 12 as data related to power consumption. The power consumption (energy charge) varies according to the operating point, that is, the discharge flow rate, even at the same frequency. In this example, however, the power consumption at the discharge flow rate in maximum load (within the range of pump selections when driven by a commercial power supply) is set as the representative point and recorded adjacent to the Q-H characteristic curves 12.

[0173] Specifically, an approximate power consumption 14a and an approximate annual energy charge 15a are recorded adjacent to the curves 12 for a frequency of 50 Hz when a commercial power source of a frequency of 50 Hz supplies power directly to the motor. An approximate power consumption 14b including heat loss from the inverter and an approximate annual energy charge 15b are recorded adjacent to the curves 12 for all other frequencies when using an inverter. The approximate power consumption 14b and the approximate annual energy charge 15b show the reduction in power consumption from the value at 50 Hz.

[0174] For example, the approximate power consumption for discharge flow rate at the maximum load point is 10.50 kW when performing operations with a commercial 50-Hz power source. Based on this value, the approximate annual energy charge calculated for an operating time of 8400 h/year at an energy charge of 13 yen/kWh is 1,150,000 yen. When using an inverter, on the other hand, the approximate power consumption when performing operations at a frequency of 45 Hz is reduced by 2.46 kW from that at a frequency of 50 Hz, resulting in a reduction of 269,000 yen in the approximate annual energy charge.

[0175] The price 16 of the inverter is also displayed on the surface (display material) 11, and in this example, the price 16 of the inverter is 498,000 yen. Thus, as described above, it is found that in case of operating the pump at a frequency of 45 Hz in place of the commercial 50-Hz power source, the investment (or cost) of the inverter can be

recovered by 1.85 year (489,000/269,000).

[0176] Here, it is necessary to consider that the operating time and energy charge (cost/kWh) vary according to the work site and region and that an investment is required for installing the inverter. However, calculating the return of investment or cost-effectiveness is remarkably easier with the present invention than with the conventional method of displaying pump characteristics.

[0177] A selection range 17 for pumps driven by the commercial power is the area enclosed by a dotted line on the surface (display material) 11. The selection range 17 facilitates studying the feasibility of replacing the current pump with a pump having one class smaller capacity. The same display described above can be achieved on a flat display surface, such as a space in a catalog for one class smaller capacity pump. Although not shown in the diagram, displaying the cost of the pumps on the surface 11 would facilitate comparing the return of investment or cost-effectiveness of replacing the current pump with one class smaller capacity pump to that of adding an inverter.

[0178] Further, calculating conditions 18 for data regarding power consumption are included on the surface 11. In this example, the calculating conditions 18 include an operating time of 8400 h/year and an energy charge of 13 yen/kWh. This data allows the user to perform simple multiplication and division calculations in case of different operating times and the like.

[0179] Next, an example of calculating a simple return of investment or cost-effectiveness of introducing an inverter will be described with reference to FIGS. 37 and 38. FIG. 38 shows an example of a pump requirement 19 only needed in emergency situations and an example of a normal operation pump requirement 20 indicated by a double circle and a single circle, respectively, on the surface 11 of FIG. 37. In this example, one class smaller capacity pump is sufficient when considering most operating conditions (requirements), but a pump is selected with consideration for requirements in emergency situations.

[0180] As an example, it is assumed that the operating time for normal operation requirements is 6000 h/year, with an energy charge of 20 yen/kWh. In this case, the operating frequency can be set to 40 Hz, and hence as shown in FIGS. 37 and 38, the power consumption of 4.86 kW can be reduced compared to that when an inverter is not used. Accordingly, the annual energy charge can be calculated by 4.86 kW × 6000 h/year × 20 yen/kWh, which equals a reduction of 583,200 yen.

[0181] Since the cost of an inverter is 498,000 yen, with consideration for the cost of installing the inverter, the investment can be recovered in approximately one year. In this manner, the present invention enables the user to find the return of investment or cost-effectiveness for introducing an inverter in an extremely short time.

[0182] Next, a method and material for displaying characteristics of the fluid machinery according to a second embodiment of the present invention will be described with reference to FIG. 39. The display according to the second embodiment includes more detailed data on power consumption. In addition to entering the approximate annual energy charge 15 adjacent to the curves 12, the surface 11 also includes a separate graph with a plurality of power consumption curves 21 showing the relationship between power consumption and discharge flow rate for each frequency supplied to the motor, and a reduction ratio (%) 22 and the approximate power consumption 14 described in the first embodiment adjacent to the power consumption curves 21.

[0183] By reading the power consumption curves 21 using the display method and material according to the present embodiment, it is possible to calculate with great accuracy the return of investment or cost-effectiveness and the absolute value of energy savings when incorporating an inverter.

[0184] Next, a method and material for displaying characteristics of the fluid machinery according to a third embodiment of the present invention will be described with reference to FIG. 40. In this embodiment, the curves 12 and a plurality of equivalent power consumption curves 23 for each power consumption approximately determined by the rotational speed (frequency) and discharge flow rate are displayed on the same coordinate system. The equivalent power consumption curves 23 are depicted by dotted lines. Further, an annual energy charge 24 is displayed numerically adjacent to the equivalent power consumption curves 23.

[0185] The display method and material according to the present embodiment has the effect of combining the graphs in FIGS. 37 and 39.

[0186] Next, a calculating and graphing system for obtaining the display material or power consumption line graphs shown in FIGS. 37 through 40 will be described. The displayed results are obtained by inputting the flow rate-pressure characteristics and flow rate-power consumption data for fluid machinery having a motor driven by a commercial AC power.

[0187] The hardware configuration for the calculating and graphing system is the same as that shown in FIG. 1. The calculating and graphing system comprises a main controller 1 for controlling the overall system, and a main storage unit 2 connected to the main controller 1. The main controller 1 includes a control unit 3 and an arithmetic unit 4. The main controller 1 is also connected to an input device 5 including a keyboard, mouse, or the like and an output device 6 including a printer, display, or the like. In FIG. 1, the bold arrows show the flow of data and programs, while the thin arrows indicate the flow of control signals.

[0188] The main controller 1 has an internal memory (not shown) for storing control programs such as an operating

system, a program prescribing the diagnostic procedure for the fluid machinery, and required data. These programs implement a calculating process and a graphing process for creating the display material. The main storage unit 2 includes a hard disk, floppy disk, optical disk, or the like.

[0189] FIG. 41 is a flow chart showing an outline of the process flow performed in the calculating and graphing system of FIG. 1.

[0190] In step 1, data regarding the flow rate-head characteristics and the flow rate-power consumption characteristics for the rotational speed of fluid machinery having a motor driven by a commercial AC power is inputted into the input device 5. This data may be prepared and stored in the main storage unit 2.

[0191] In step 2, calculations are performed to find the flow rate-head characteristics and the flow rate-power consumption characteristics for a plurality of rotational speeds different from the rotational speed inputted in step 1. The calculation is performed according to the expression (1) described above. In this case, it is also possible to input measured data for various rotational speeds in place of performing the calculation.

[0192] In step 3, data regarding the operating time of the fluid machinery and the energy charge per unit of power consumption is inputted into the input device 5.

[0193] In step 4, a plurality of flow rate-head characteristic curves for various rotational speeds are displayed on the output device 6, along with data related to power consumption. As described above, the output device 6 comprises a printer, or a display such as LCD. The power consumption related data includes the various data shown in FIGS. 37 through 40.

[0194] The calculating and graphing system implemented by a personal computer has the same structure as that shown in FIG. 36. This system includes a personal computer PC comprising a main controller 1 (having a control unit 3 and an arithmetic unit 4), a main storage unit 2, an input device 5, and an LCD forming part of the output device 6, all of which are shown in FIG. 1; a floppy disk FD or CD-ROM serving as the storage medium for storing the above programs; and a printer PR forming another part of the output device 6.

[0195] In the example of the present embodiment, the surface for displaying the characteristics of the fluid machinery is described as a flat surface. However, a curved surface is also possible, providing the surface is continuous. Further, this display surface is not limited to the surface of a paper such as part of a catalog, but may also be a liquid crystal display or the like.

[0196] With the present invention described above, the user can easily find expected energy savings and the time required to recover an initial investment by recording fluid machinery characteristic curves on a pump or inverter catalog or the like, without performing complex calculations. Accordingly, the present invention has the effect of creating a demand for inverters used in fluid machinery, and the inverter-mounted pumps which are recently being common, thereby helping popularize energy conserving equipment on the market.

**Industrial Applicability**

[0197] The present invention relates to a system for finding wasteful energy consumption in a fluid machinery and can be applied to equipment using cooling-water circulating pumps, feed water pumps, and the like.

**Claims**

1. A diagnostic System for fluid machinery comprising:

    first identifying means for inputting prescribed data on the fluid machinery to be diagnosed and identifying the characteristics of the fluid machinery represented by flow rate-head characteristics;
    second identifying means for identifying the operating flow rate or operating pressure of the fluid machinery according to the relationship between the identified characteristics of the fluid machinery and a measured operating pressure or operating flow rate of the fluid machinery by operating the fluid machinery to be diagnosed and inputting the measured results of the operating pressure (head), operating flow rate, power consumption, or operating electric current of the fluid machinery in operation; and
    processing means for computing variations in the operating flow rate, operating pressure, or power consumption while the rotational speed of the fluid machinery to be diagnosed is varied, and for displaying the computed results.

2. A diagnostic system for fluid machinery as claimed in claim 1, wherein said first identifying means functions by inputting one or more of the following data (1-11) regarding the fluid machinery:

    1. Diameter (or numerical order) of suction port
    2. Diameter (or numerical order) of discharge port

3. Rated output of motor driving the fluid machinery
4. Number of poles of motor driving the fluid machinery
5. Operating frequency of motor driving the fluid machinery
6. Rating plate specifications (flow rate-head) of the fluid machinery
7. Model name of the fluid machinery
8. Manufacturer's name of the fluid machinery
9. Number of impeller stages of the fluid machinery
10. Outer diameter of impeller of the fluid machinery
11. Test data regarding the flow rate-head and flow rate-power consumption of the fluid machinery.

**3.** A diagnostic system for fluid machinery as claimed in claim 1, wherein said characteristics of the fluid machinery identified by said first identifying means are refined by inputting the power consumption at the actual operating point.

**4.** A diagnostic system for fluid machinery as claimed in claim 3, wherein said characteristics of the fluid machinery identified by said first identifying means are refined by inputting the operating pressure and/or power consumption at the shutoff operating point separate from the actual operating point.

**5.** A diagnostic system for fluid machinery as claimed in claim 1, wherein said computed results obtained by said processing means are refined by inputting values of actual head.

**6.** A diagnostic system for fluid machinery capable of finding with high accuracy wasteful energy consumption in the fluid machinery and its peripheral devices, comprising:

a controller having a frequency converter as a primary component for reducing the estimated wasteful energy consumption, said controller being used in combination with said diagnostic system as claimed in any one of claims 1 to 5.

**7.** A diagnostic system for fluid machinery as claimed in claim 6, wherein the rotational speed of the fluid machinery is varied by changing the frequency generated by said frequency converter with said controller, and the actual head or head loss caused by piping is found by comparing the operating pressure for each rotational speed when the valve is open to that when the valve is closed.

**8.** A recording medium capable of being read by a computer for storing programs to enable the computer to implement the functions of:

identifying the characteristics of the fluid machinery represented by flow rate-head characteristics by inputting prescribed data on the fluid machinery to be diagnosed;
identifying the operating flow rate or operating pressure of the fluid machinery according to the relationship between the identified characteristics and a measured operating pressure or operating flow rate of the fluid machinery by operating the fluid machinery to be diagnosed and inputting the measured results of the operating pressure (head), operating flow rate, power consumption, or operating electric current of the fluid machinery in operation; and
computing variations in the operating flow rate, operating pressure, or power consumption when the rotational speed of the fluid machinery to be diagnosed is varied, and displaying the computed results.

**9.** A diagnostic system for fluid machinery comprising:

first identifying means for identifying the characteristics of the fluid machinery represented by flow rate-head characteristics of the fluid machinery to be diagnosed;
second identifying means for identifying the actual operating point of the fluid machinery to be diagnosed; and
processing means for computing variations in the operating point when the rotational speed of the fluid machinery to be diagnosed is varied, and for displaying the computed results.

**10.** A method for diagnosing fluid machinery comprising:

identifying the characteristics of the fluid machinery represented by the flow rate-head characteristics of the fluid machinery to be diagnosed;

identifying the actual operating point of the fluid machinery to be diagnosed;
computing variations in the operating point when the rotational speed of the fluid machinery to be diagnosed is varied; and
displaying the computed results.

11. A method for identifying characteristics of fluid machinery comprising:

calculating the bead and shaft power for flow rates by determining representative points for characteristics of fluid machinery including a representative head and representative shaft power and by determining the ratios of head and shaft power other than the representative flow rate to the representative head and representative shaft power based on the port diameter of the fluid machinery, the number of impeller stages, and the rated output and rated rotational speed of the motor used to drive the fluid machinery;
estimating provisional characteristics of the fluid machinery based on the calculated head and shaft power; and
identifying characteristics of the fluid machinery and the operating point including the operating flow rate by correcting said provisional characteristics of the fluid machinery based on measurement data including at least the head and power consumption during current operations.

12. A method for identifying characteristics of fluid machinery as claimed in claim 11, wherein said representative points are set as the flow rate producing maximum efficiency in the fluid machinery, the head calculated using estimated values of efficiency for the fluid machinery, and the rated output of the motor.

13. A method for identifying characteristics of fluid machinery as claimed in claim 11, wherein said representative points are set as the flow rate and head calculated using at least two points of standard specifications including the flow rate and head of the fluid machinery, and the rated output of the motor.

14. A method for identifying characteristics of fluid machinery as claimed in claim 12, wherein said provisional characteristics of the fluid machinery are corrected by the flow rate calculated using head and power consumption during current operations and the estimated values of efficiency for the fluid machinery and motor.

15. A method for identifying characteristics of fluid machinery as claimed in claim 12, wherein said provisional characteristics of the fluid machinery are corrected by the flow rate calculated using head and power consumption during current operations and the estimated values of efficiency for the fluid machinery and motor, and the head and power consumption during shutoff operations.

16. A method for identifying characteristics of fluid machinery as claimed in claim 12, wherein said provisional characteristics of the fluid machinery are corrected by the flow rate calculated using head and power consumption during current operations and the estimated values of efficiency for the fluid machinery and motor, and the head and power consumption during operations when the valve is fully open.

17. A method for identifying characteristics of fluid machinery as claimed in claim 12, wherein said provisional characteristics of the fluid machinery are corrected by the flow rate calculated using head and power consumption during current operations and the estimated values of efficiency for the fluid machinery and motor, and the head and power consumption during shutoff operations and during operations when the valve is fully open.

18. A method for identifying characteristics of fluid machinery as claimed in claim 13, wherein the operating point (flow rate) is identified by said provisional characteristics of the fluid machinery and the head during current operations, and said provisional characteristics are corrected by the current power consumption.

19. A method for identifying characteristics of fluid machinery as claimed in claim 13, wherein the operating point (flow rate) is identified by said provisional characteristics of the fluid machinery and the head during current operations, and said provisional characteristics are corrected by the current power consumption and the power consumption when the valve is fully open.

20. An energy-saving pre-diagnostic system for fluid machinery, comprising:

inputting means for inputting flow rate-pressure (head) and flow rate-power consumption data for fluid machinery having a motor driven by a commercial AC power, and design specifications (flow rate-pressure) in a facility

side;
inputting or estimating means for inputting or estimating resistance of piping (actual head) when the flow rate is zero;
calculating means for calculating the reduction in power consumption achieved when reducing the rotational speed of the fluid machinery with a frequency converter; and
processing means for displaying the calculated results.

21. A recording medium capable of being read by a computer for storing programs to enable the computer to implement the functions of:

inputting flow rate-pressure (head) and flow rate-power consumption data for fluid machinery having a motor driven by a commercial AC power, and design specifications (flow rate-pressure) in a facility side;
inputting or estimating resistance of piping (actual head) when the flow rate is zero;
calculating the reduction in power consumption achieved when reducing the rotational speed of the fluid machinery with a frequency converter; and
displaying the calculated results.

22. A method for displaying the characteristics of fluid machinery, comprising:

displaying the flow rate-pressure characteristics of the fluid machinery varied according to the rotational speed on the same surface using a plurality of curves; and
displaying data related to the power consumption on the same surface.

23. A method for displaying the characteristics of fluid machinery as claimed in claim 22, further comprising numerically displaying data related to the power consumption adjacent to each curve representing the fluid-pressure characteristics.

24. A method for displaying the characteristics of fluid machinery as claimed in claim 22 or 23, further comprising displaying on the same surface a reference selection range under a fixed rotational speed of the fluid machinery.

25. A method for displaying the characteristics of fluid machinery as claimed in any one of claims 22 to 24, further comprising displaying on the same surface data related to the power consumption, including at least one of the energy charge or the amount of reduction in the energy charge.

26. A method for displaying the characteristics of fluid machinery as claimed in any one of claims 22 to 25, further comprising displaying on the same surface at least one of the cost of the fluid machinery or the cost of the apparatus required to vary the rotational speed.

27. A method of displaying the characteristics of fluid machinery as claimed in any one of claims 22 to 26, further comprising displaying on the same surface conditions for calculating data related to the power consumption.

28. A display material for displaying the characteristics of the fluid machinery using the method as claimed in any one of claims 22 to 27.

29. A fluid machinery or an apparatus for varying the rotational speed of the fluid.machinery, comprising:

displaying the flow rate-pressure characteristics of the fluid machinery varied according to the rotational speed on the same surface of a promotional material represented by a catalog, using a plurality of curves; and
displaying data related to the power consumption on the same surface of said promotional material.

30. A line graph for the power consumption of fluid machinery comprising:

a plurality of curves indicating the flow rate-pressure characteristics of fluid machinery in each of rotational speeds and displayed in a coordinate system; and
a plurality of curves indicating the flow rate-pressure characteristics of the fluid machinery in each of values of power consumption and displayed in said coordinate system.

31. A calculating and graphing system, comprising a computer for obtaining the display material of claim 28 or the line

graph of claim 30, by inputting data for the flow rate-pressure characteristics and flow rate-power consumption characteristics of fluid machinery having a motor driven by a commercial AC power.

32. A recording medium capable of being read by a computer for storing programs to enable the computer to implement the calculating and graphing system as claimed in claim 31.

FIG. 1

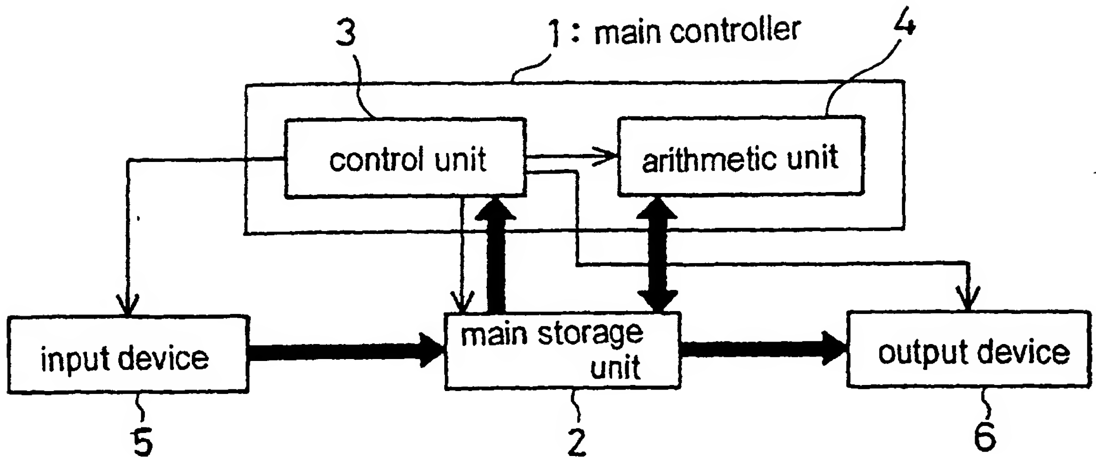

3
1 : main controller
4
control unit
arithmetic unit
input device
main storage unit
output device
5
2
6

FIG. 2

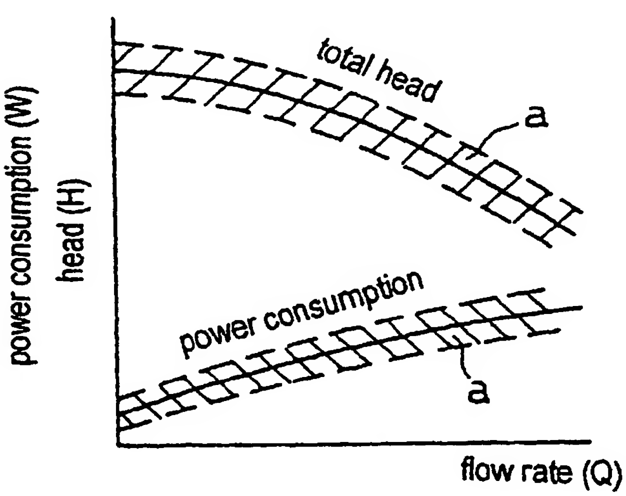
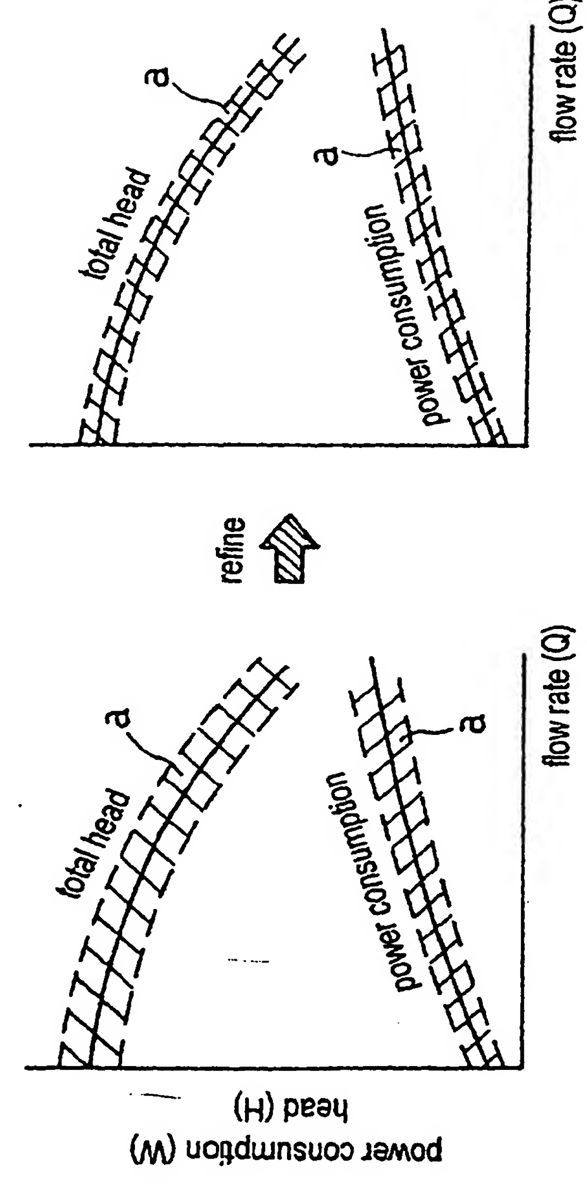

power consumption (W)
head (H)
total head
a
power consumption
a
flow rate (Q)

FIG. 3A

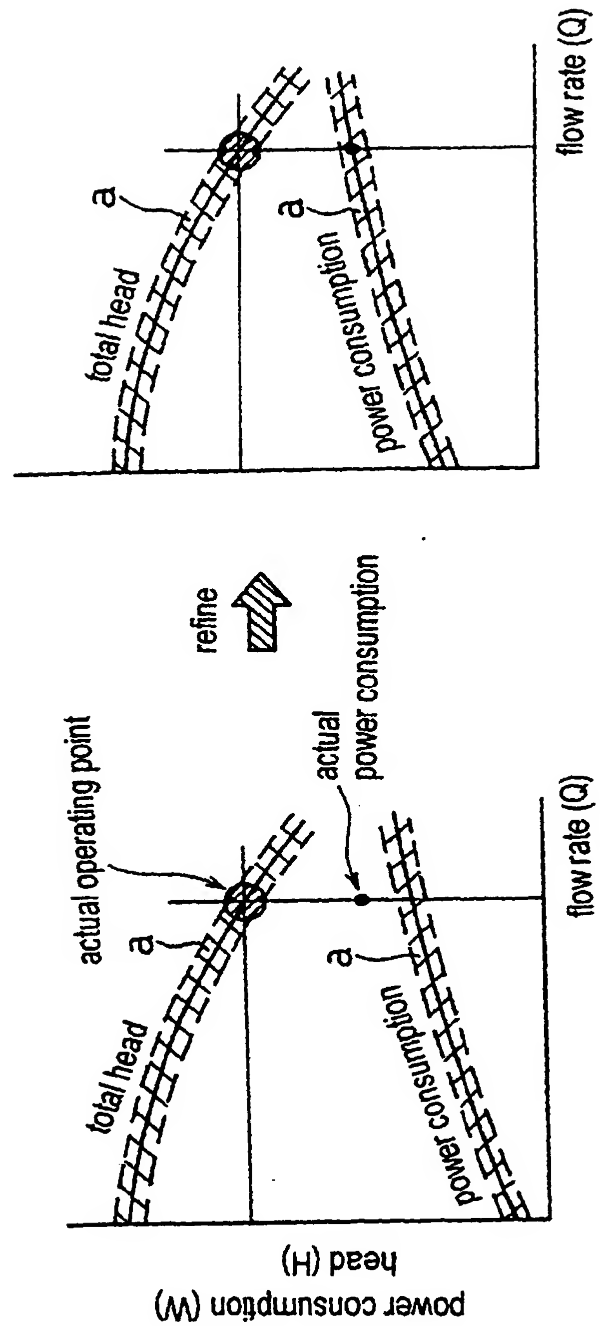
FIG. 3B



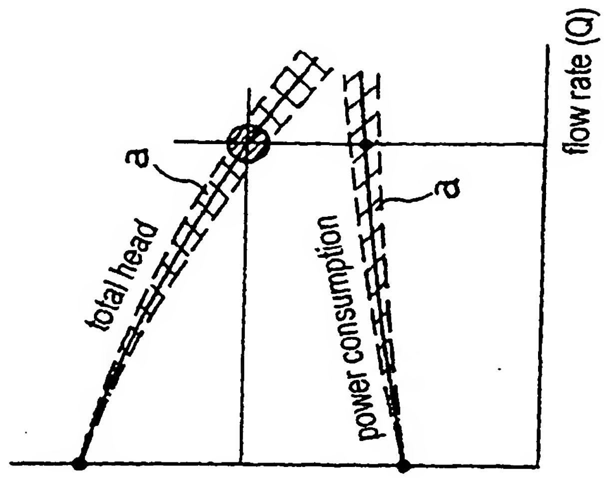
total head
a
power consumption
a
flow rate (Q)
head (H)
power consumption (W)
refine
total head
a
power consumption
a
flow rate (Q)

F I G. 4A

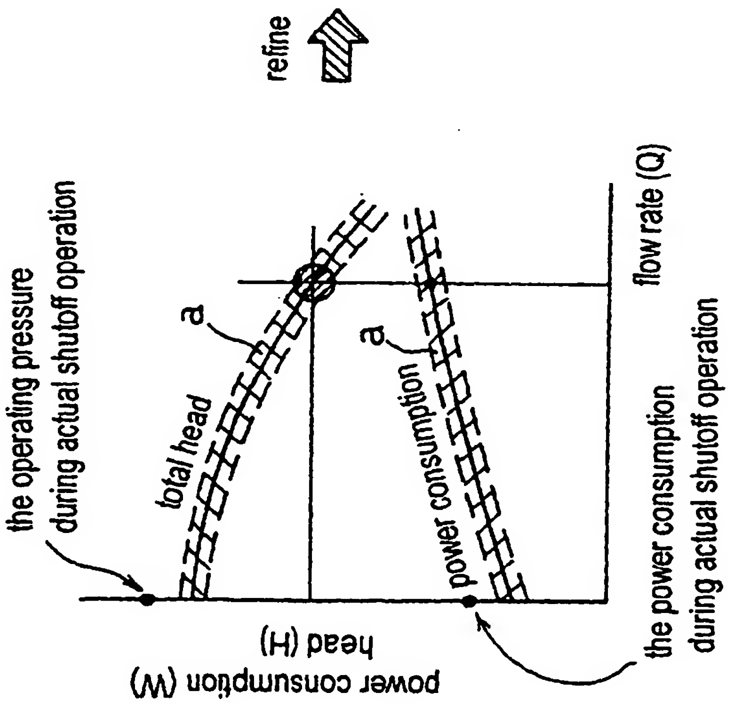
F I G. 4B


total head
a
actual operating point
actual power consumption
power consumption
a
flow rate (Q)
power consumption (M)
head (H)
refine
total head
a
power consumption
a
flow rate (Q)

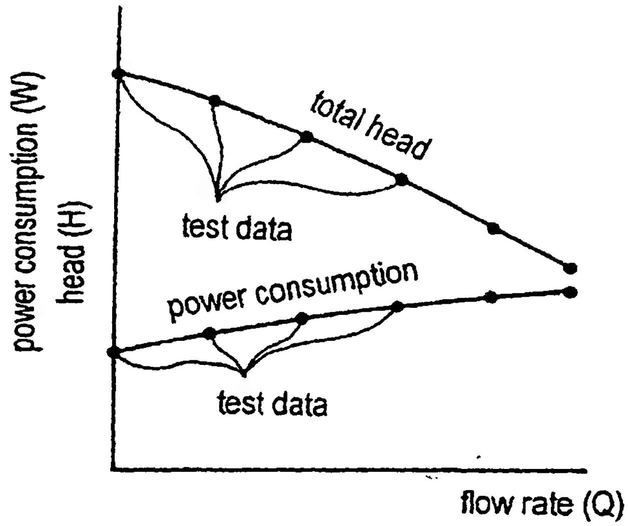
F I G. 5 B


total head
a
power consumption
a
flow rate (Q)

F I G. 5 A


refine
the operating pressure
during actual shutoff operation
total head
a
power consumption
a
power consumption (W)
head (H)
flow rate (Q)
the power consumption
during actual shutoff operation

F I G. 6


power consumption (W)
head (H)
total head
test data
power consumption
test data
flow rate (Q)

F I G. 7

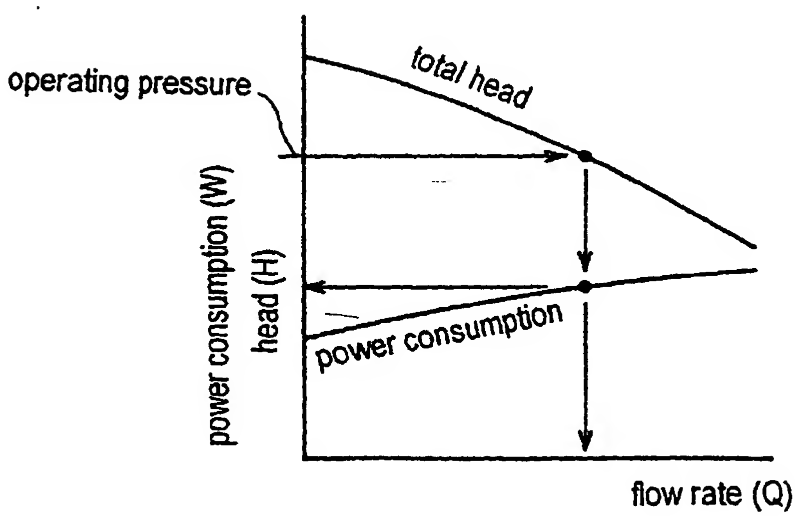

operating pressure
total head
power consumption (W)
head (H)
power consumption
flow rate (Q)

FIG. 8

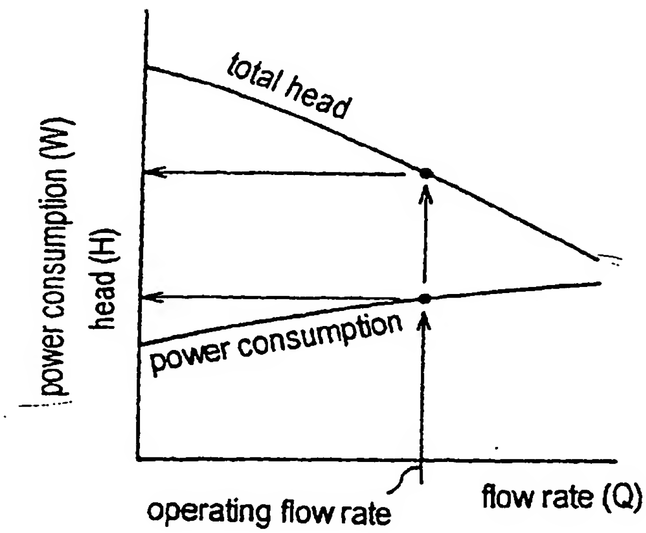

total head
power consumption (W)
head (H)
power consumption
operating flow rate
flow rate (Q)

FIG. 9

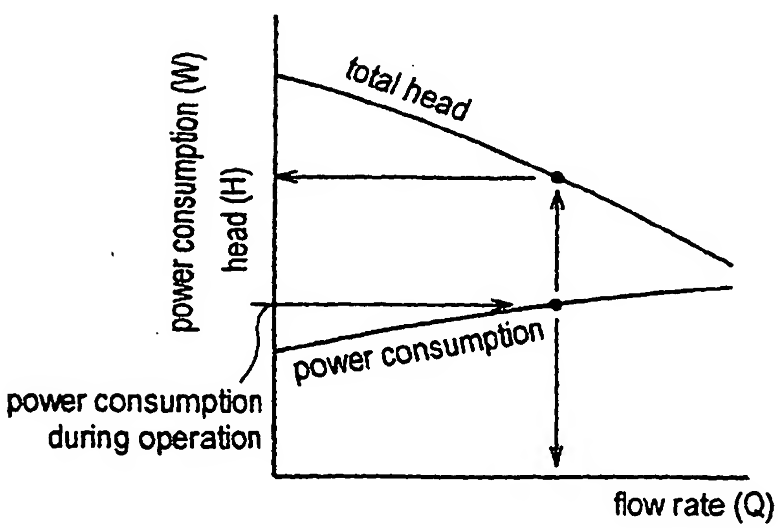

total head
power consumption (W)
head (H)
power consumption
power consumption
during operation
flow rate (Q)

FIG. 10

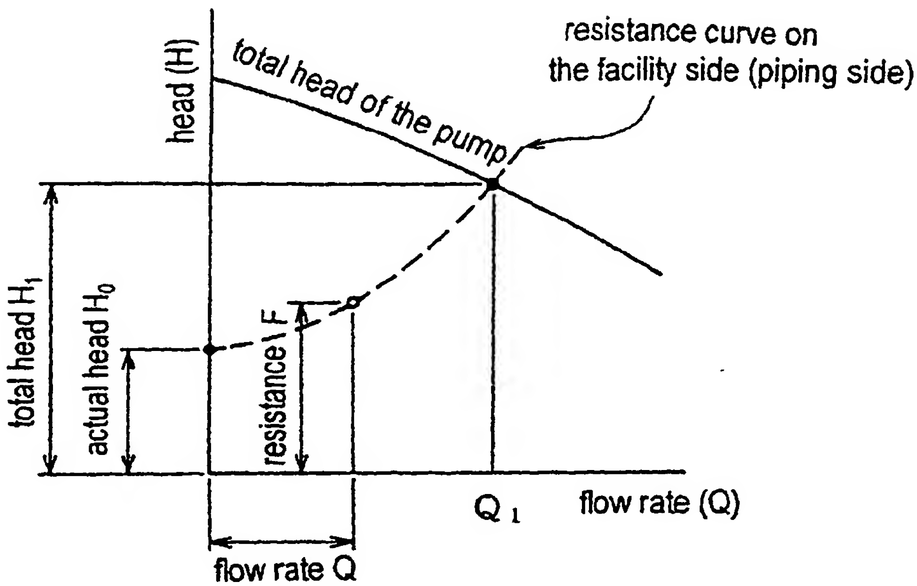

head (H)
total head of the pump
resistance curve on
the facility side (piping side)
total head $H_1$
actual head $H_0$
resistance F
$Q_1$
flow rate (Q)
flow rate Q

FIG. 11

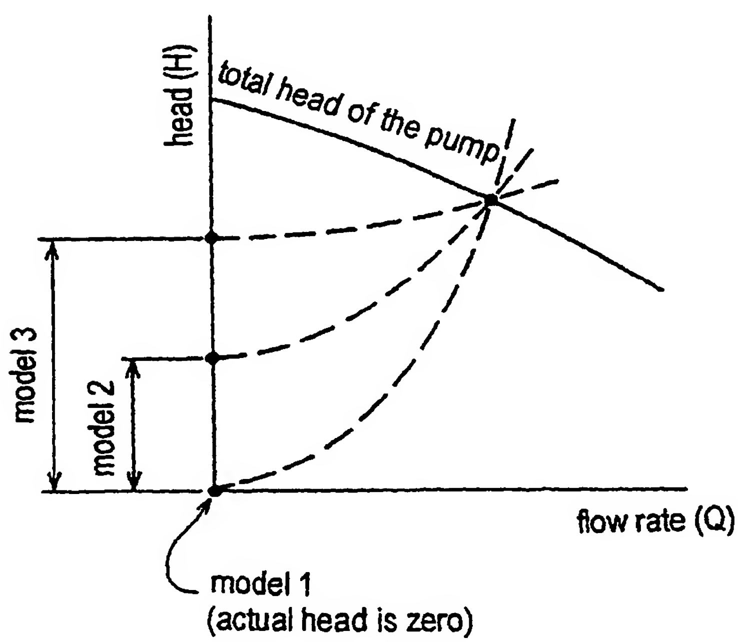

head (H)
total head of the pump
model 3
model 2
flow rate (Q)
model 1
(actual head is zero)

FIG. 12

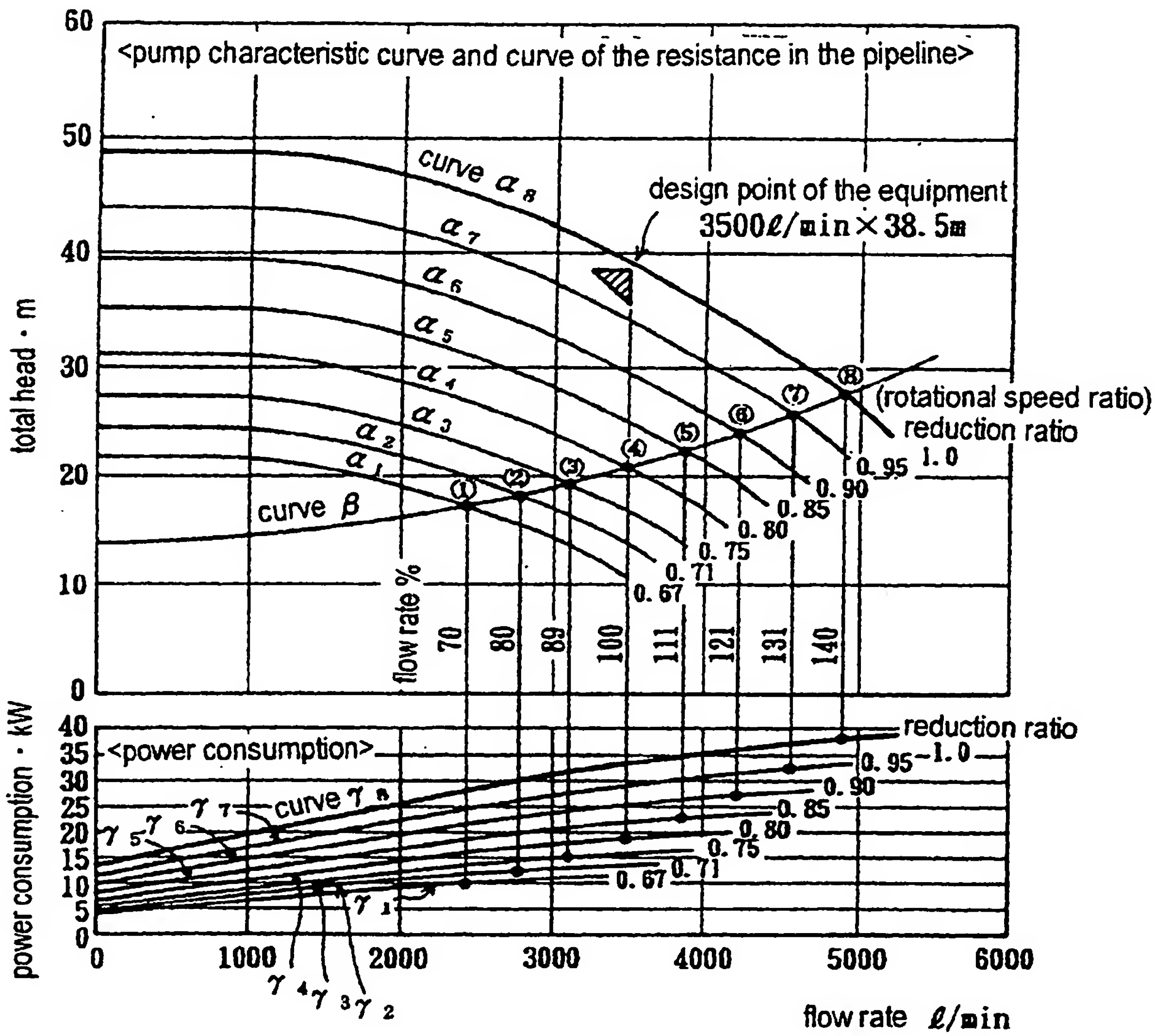

<pump characteristic curve and curve of the resistance in the pipeline>
design point of the equipment
3500ℓ/min×38.5m
curve α8
α7
α6
α5
α4
α3
α2
α1
curve β
(rotational speed ratio)
reduction ratio
1.0
0.95
0.90
0.85
0.80
0.75
0.71
0.67
flow rate %
70
80
89
100
111
121
131
140
total head · m
<power consumption>
curve γ8
γ7
γ6
γ5
γ4
γ3
γ2
γ1
power consumption · kW
flow rate ℓ/min
0
1000
2000
3000
4000
5000
6000

FIG. 13

data for identifying the characteristics of the fluid machinery which is to be diagnosed and is actually in operation is inputted (step 1)

↓

data for identifying the operating point of the fluid machinery which is actually in operation is inputted (step 2)

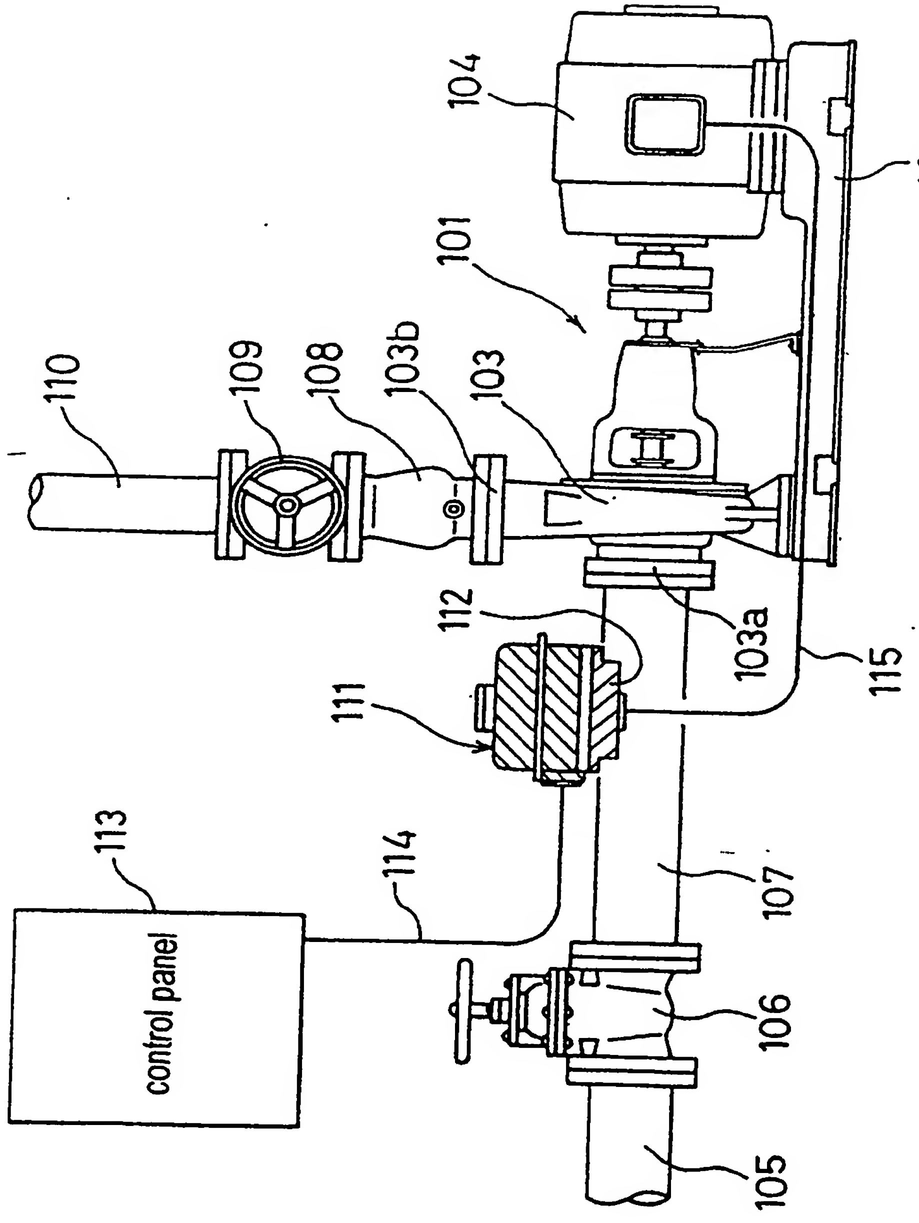
↓

data for identifying resistance characteristics on the facility side is inputted (step 3)

↓

the transition of the operating point for the fluid machinery caused by a change in the rotational speed of the fluid machinery is calculated and displayed (step 4)

FIG. 14



control panel
113
114
111
112
110
109
108
103b
103
101
104
102
103a
115
107
106
105

FIG. 15

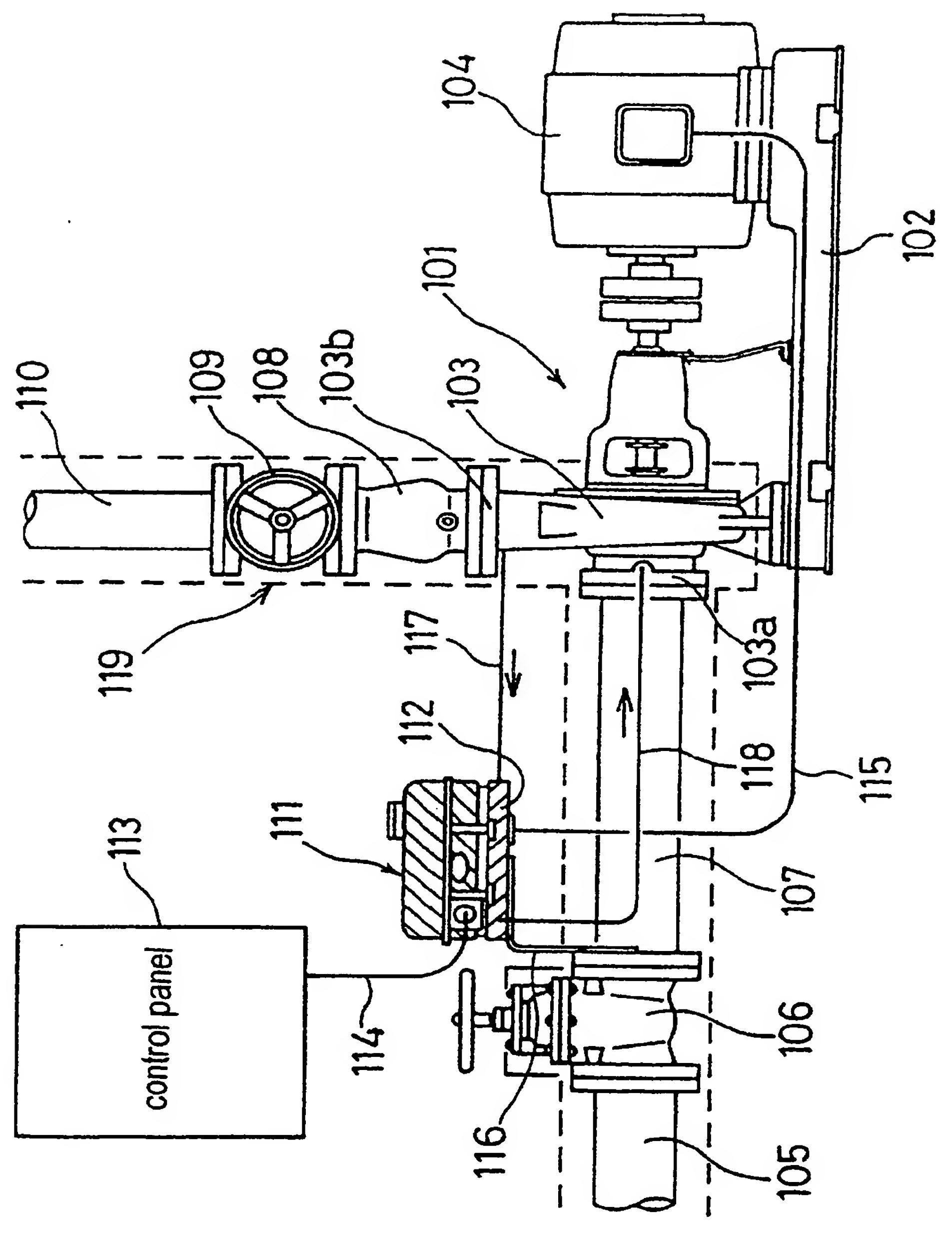

110
109
108
103b
103
101
104
102
119
117
103a
112
118
115
111
113
control panel
107
114
106
116
105

FIG. 16A

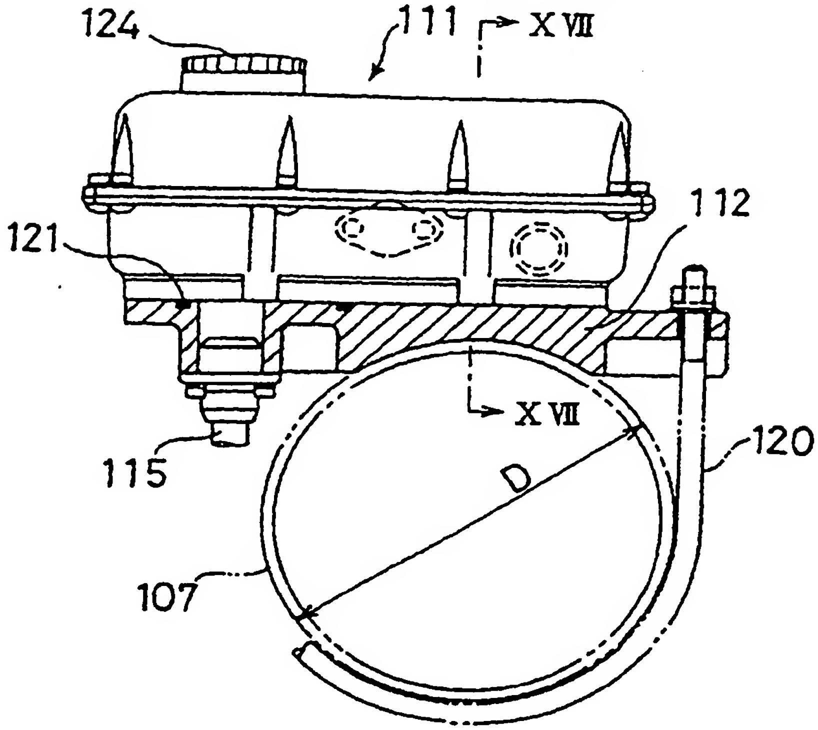



FIG. 16B

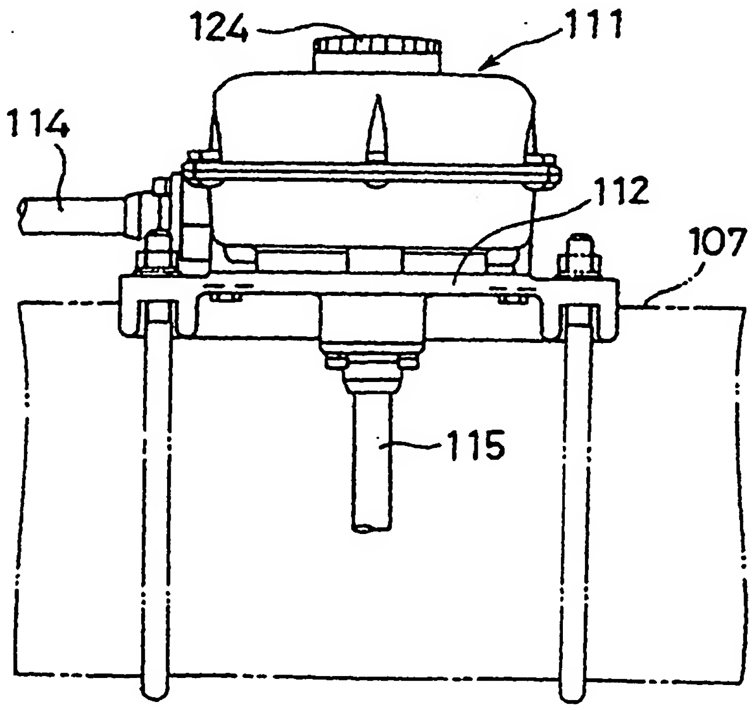
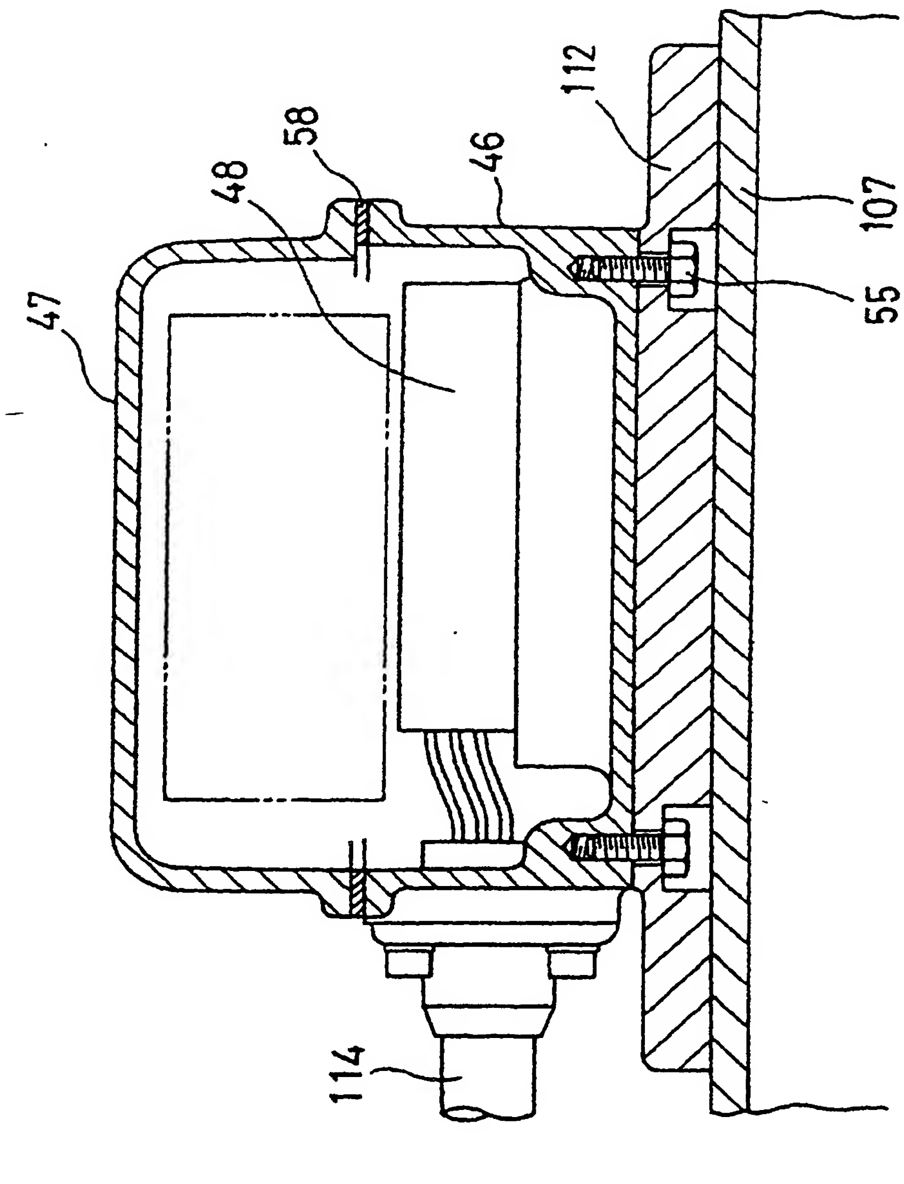
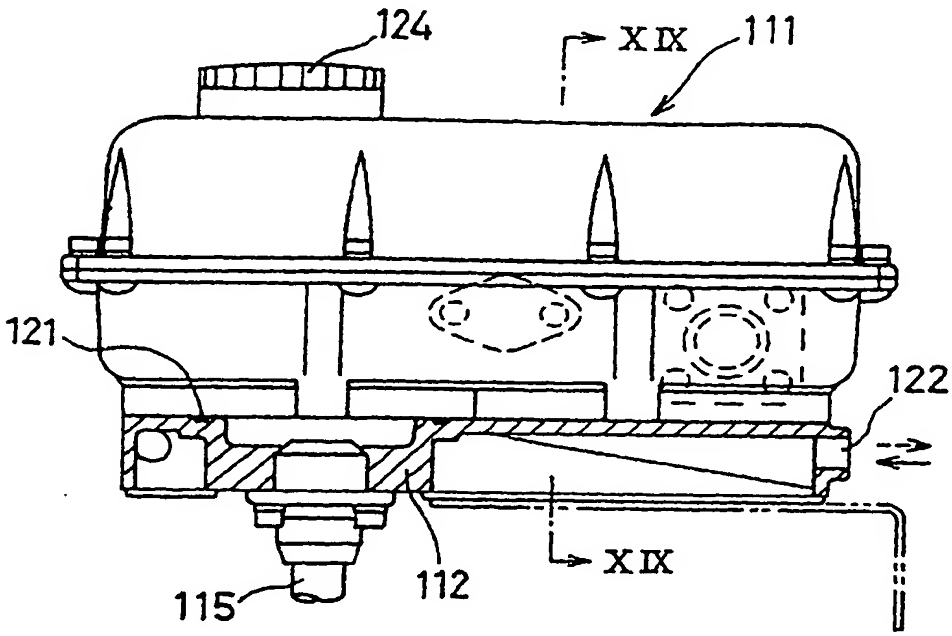


FIG. 17



F I G. 1 8A




F I G. 1 8B

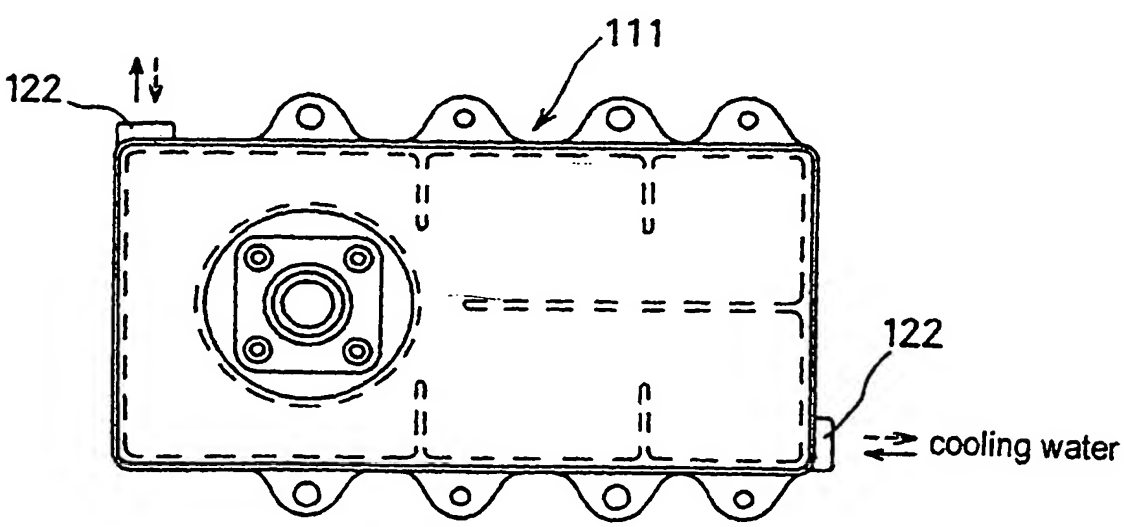


FIG. 19

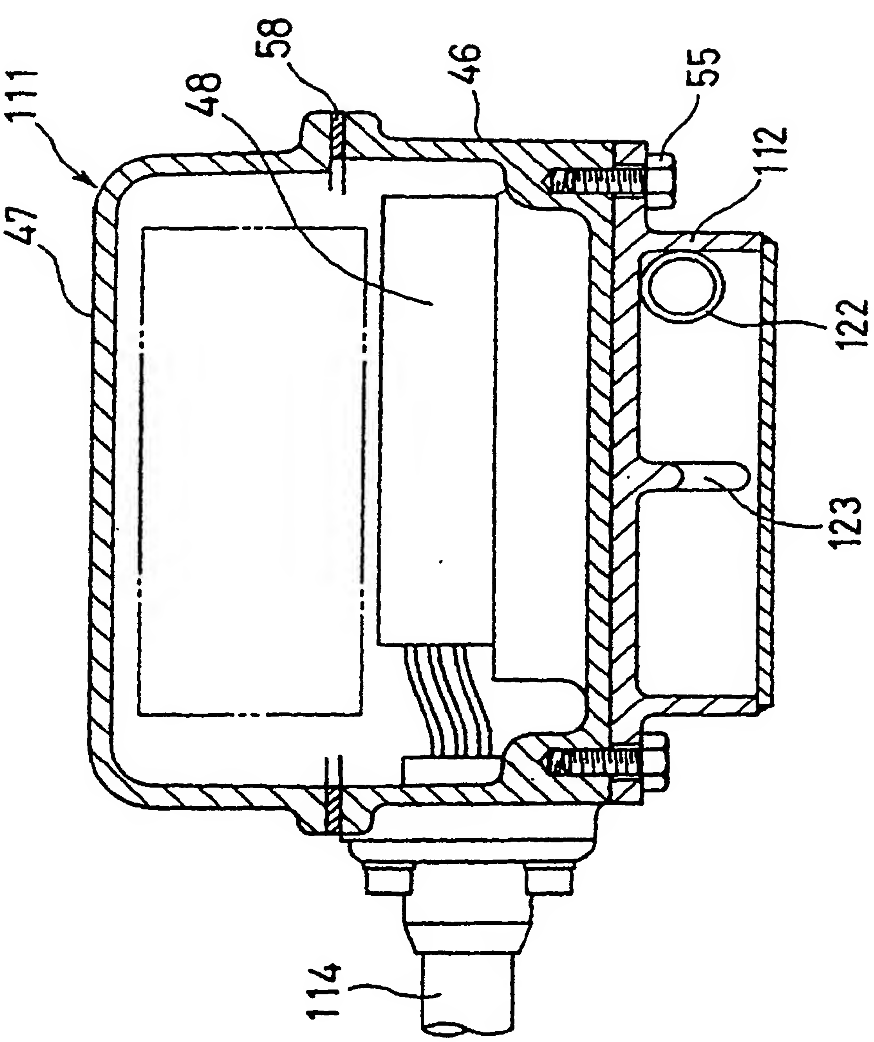


FIG. 20A

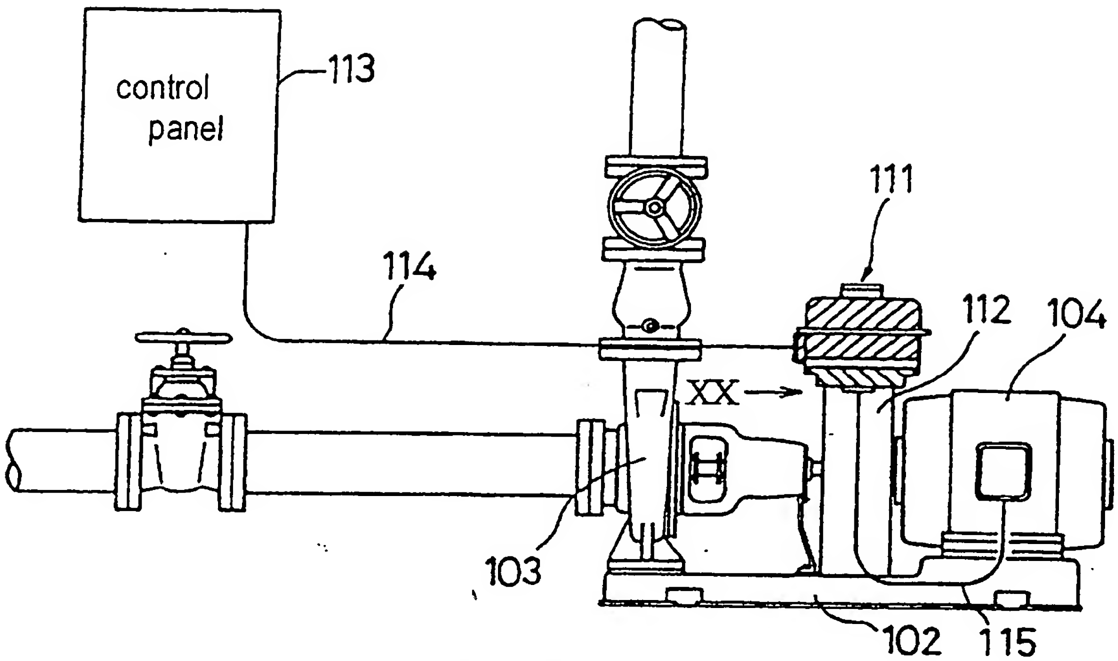
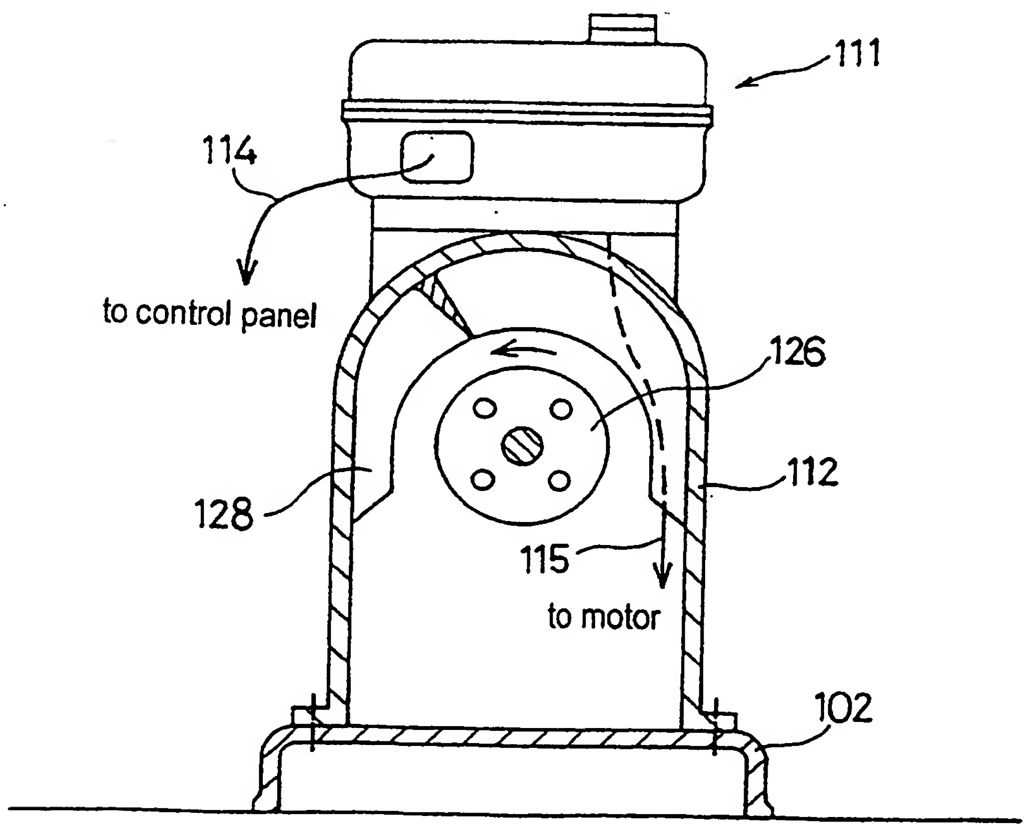
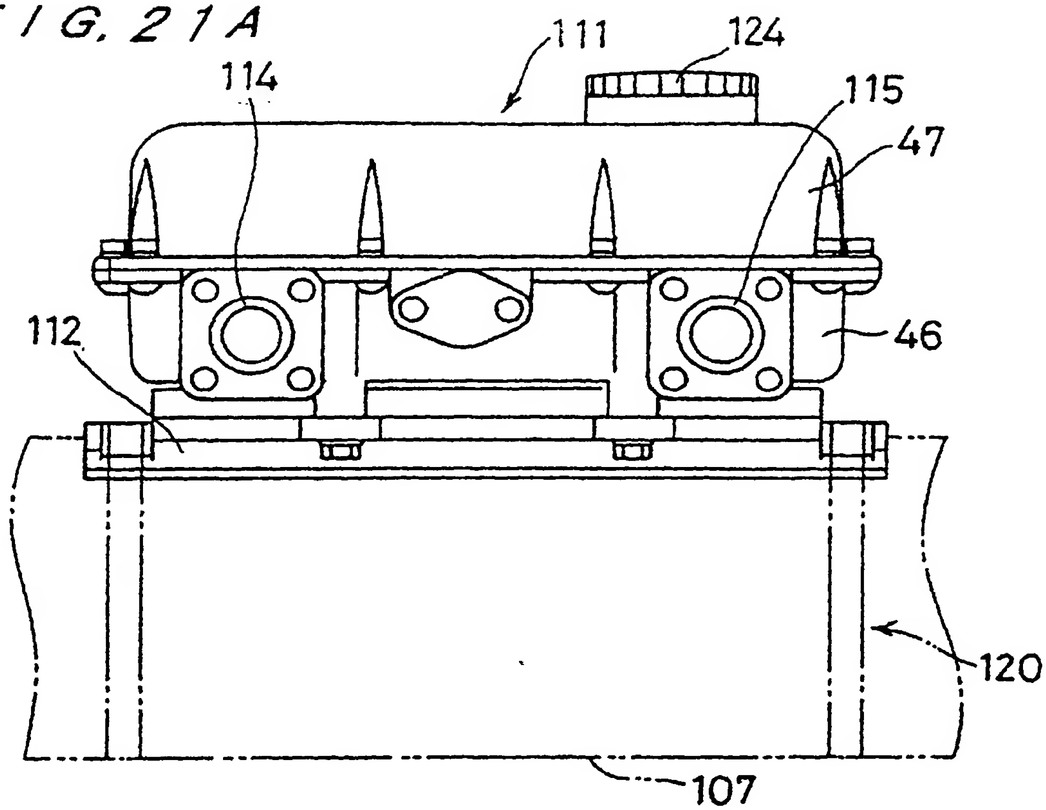


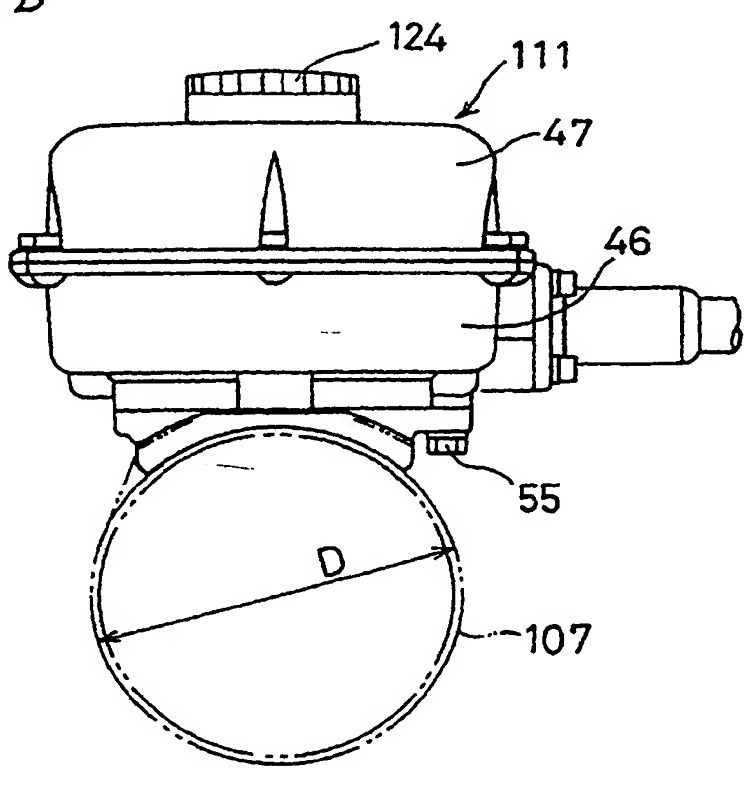

FIG. 20B



F I G. 2 1 A




F I G. 2 1 B



F I G. 2 2

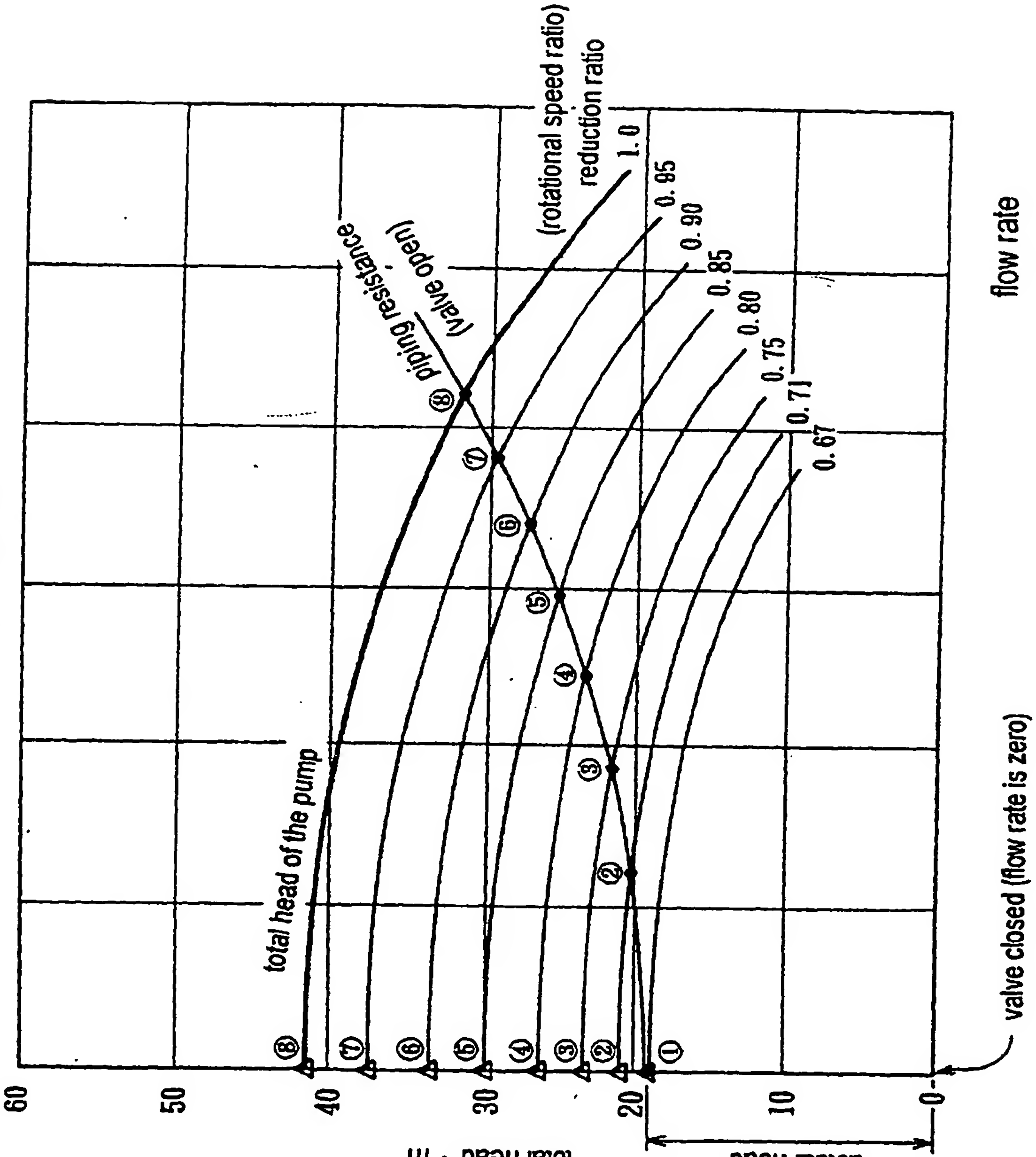

(rotational speed ratio)
reduction ratio
1.0
0.95
0.90
0.85
0.80
0.75
0.71
0.67
piping resistance
(valve open)
total head of the pump
flow rate
valve closed (flow rate is zero)
total head · m
actual head
60
50
40
30
20
10
0
①
②
③
④
⑤
⑥
⑦
⑧

FIG. 23

equipment that can be carried to the operating site of the fluid machinery

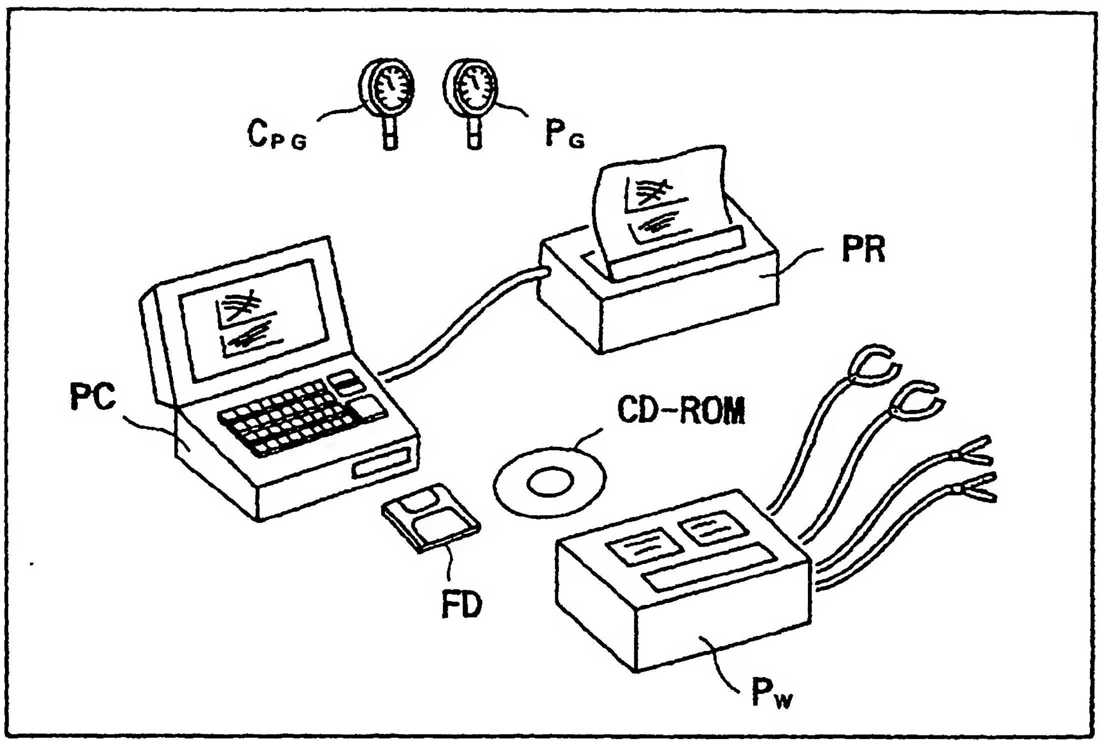


FIG. 24

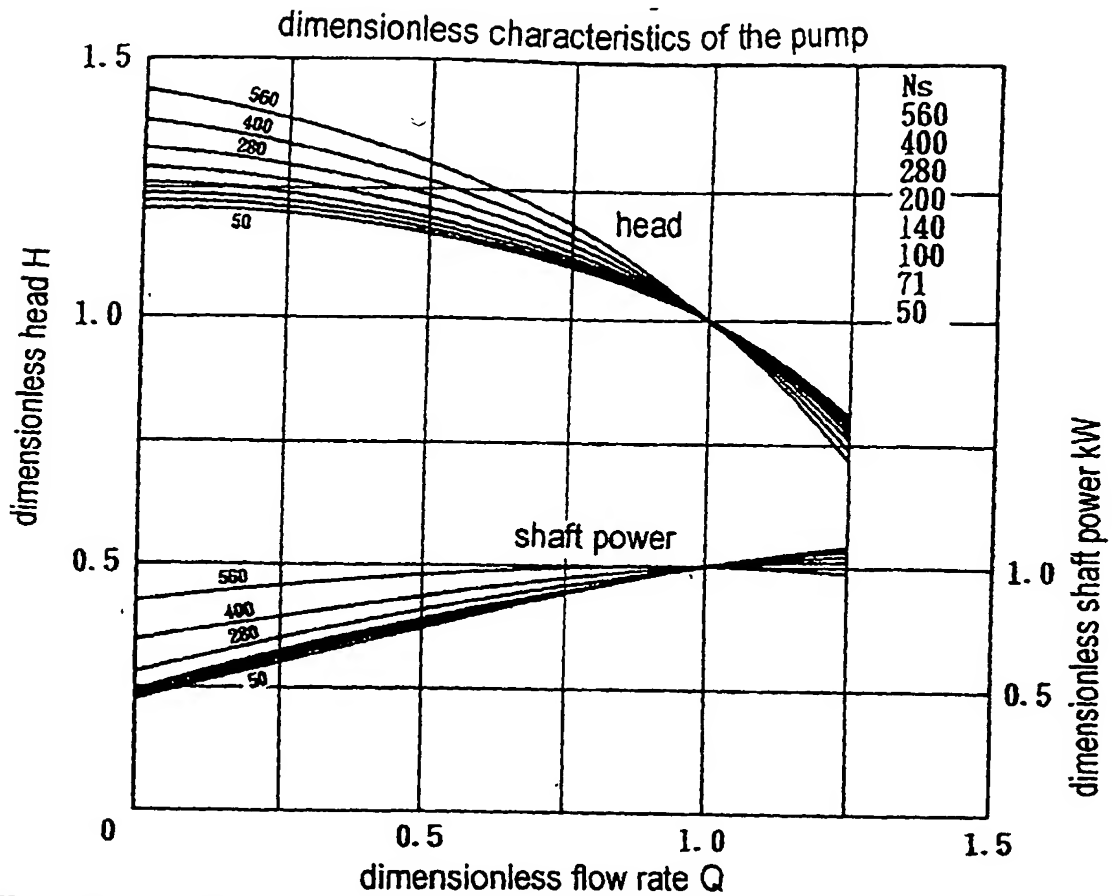
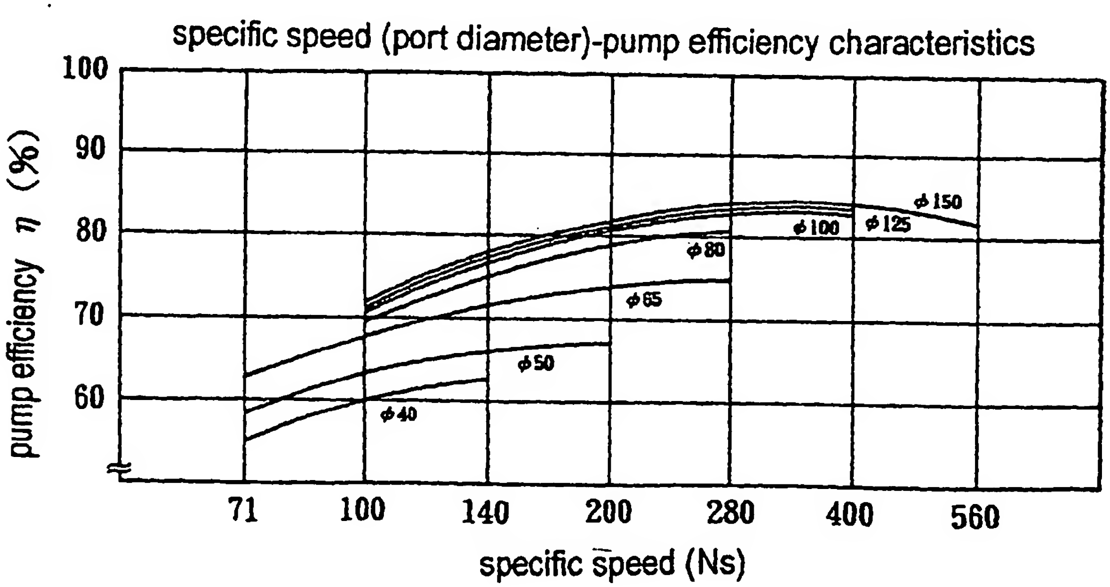

dimensionless characteristics of the pump
1.5
1.0
0.5
0
dimensionless head H
head
shaft power
Ns
560
400
280
200
140
100
71
50
1.0
0.5
dimensionless shaft power kW
0.5
1.0
1.5
dimensionless flow rate Q

FIG. 25


specific speed (port diameter)-pump efficiency characteristics
100
90
80
70
60
pump efficiency η (%)
φ150
φ125
φ100
φ80
φ65
φ50
φ40
71
100
140
200
280
400
560
specific speed (Ns)

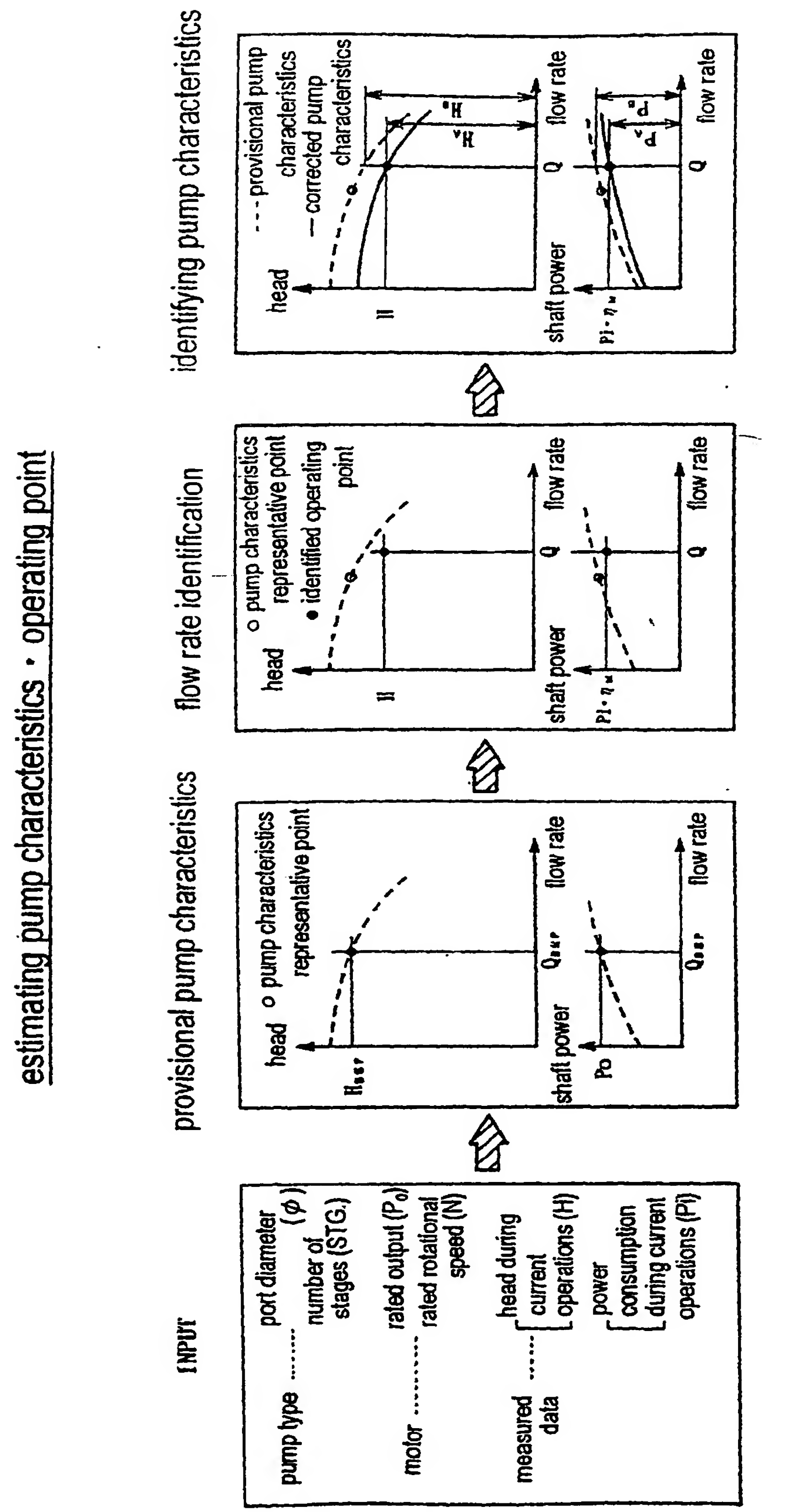


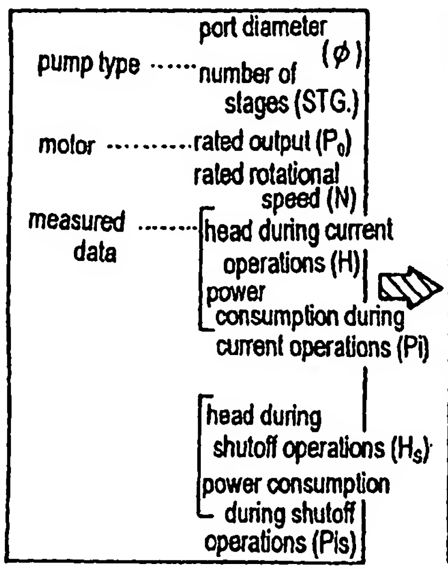

FIG. 26A

FIG. 26B

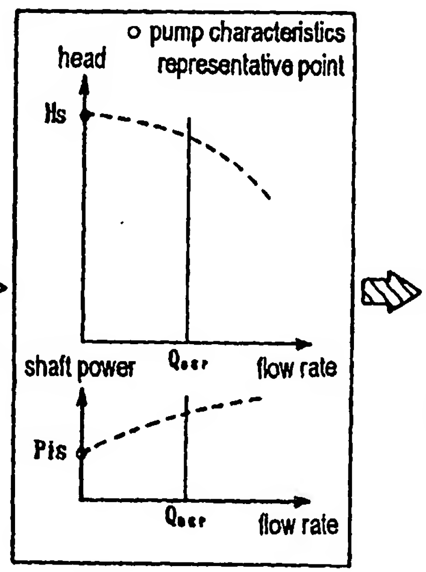
FIG. 26C

FIG. 26D

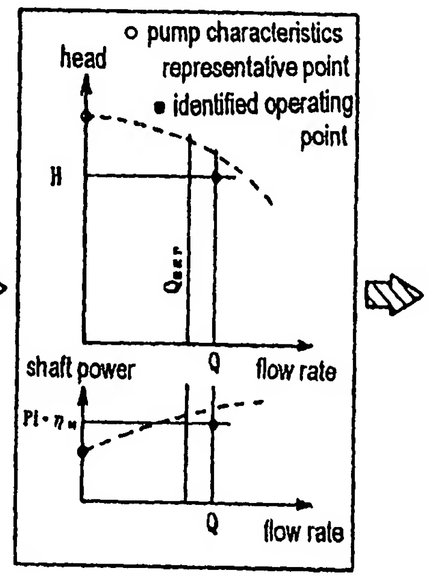
estimating pump characteristics · operating point



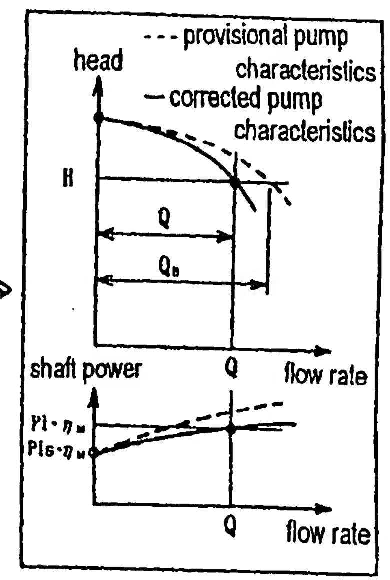

F I G. 2 7 A



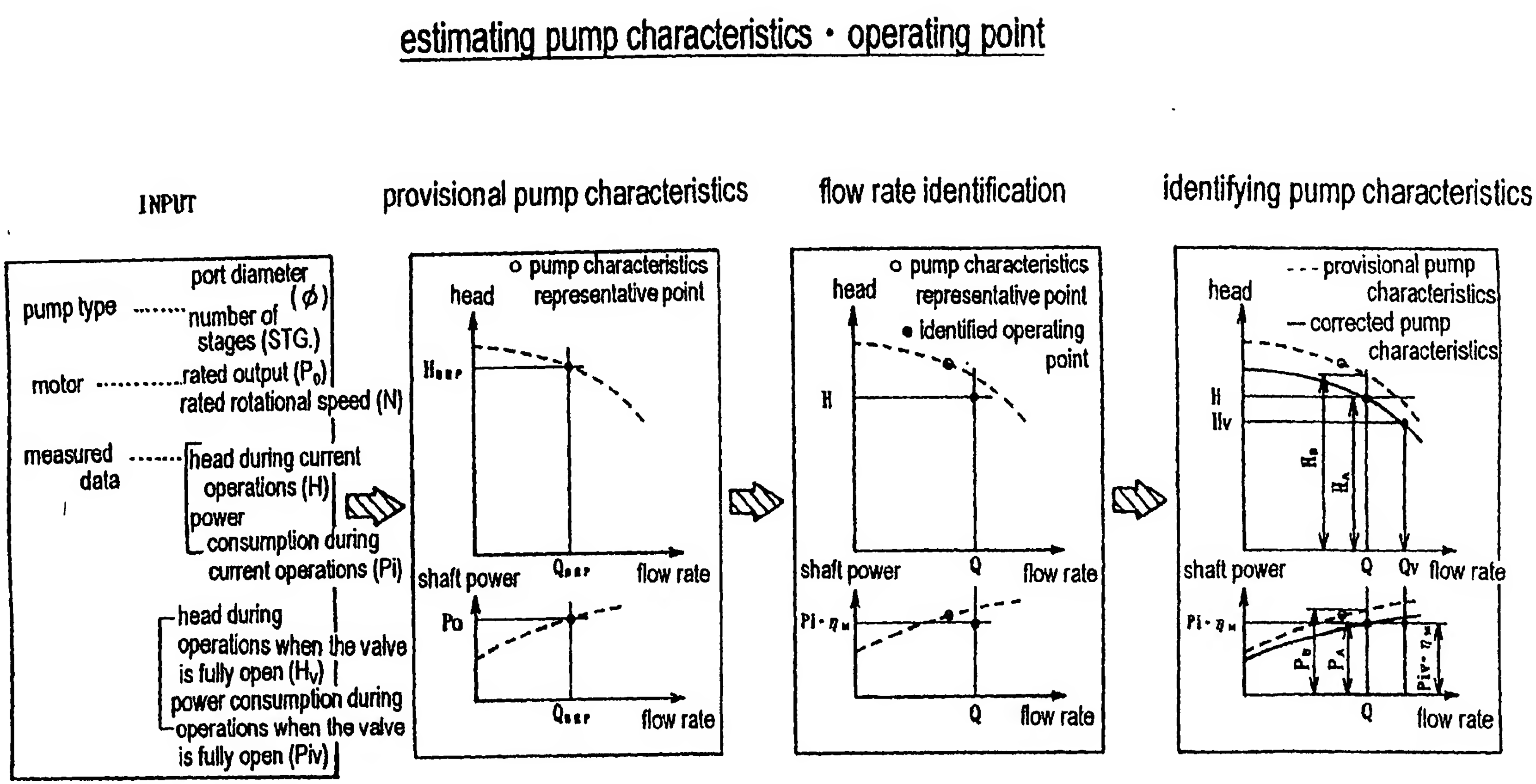

F I G. 2 7 B




F I G. 2 7 C



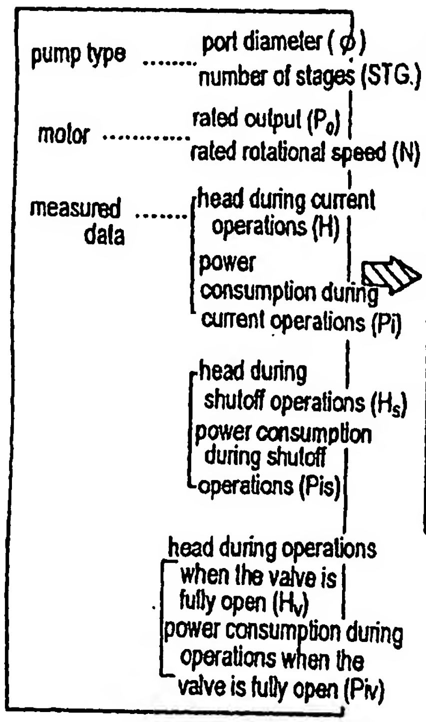

F I G. 2 7 D




F I G. 28A F I G. 28B F I G. 28C F I G. 28D

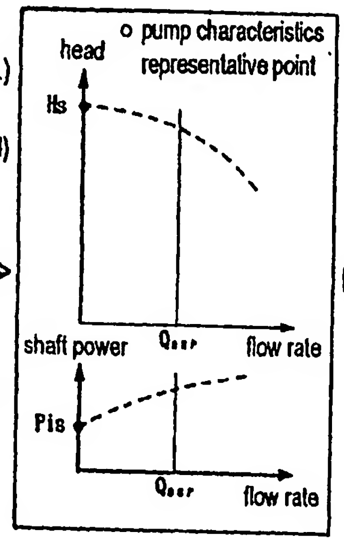
## estimating pump characteristics · operating point

INPUT



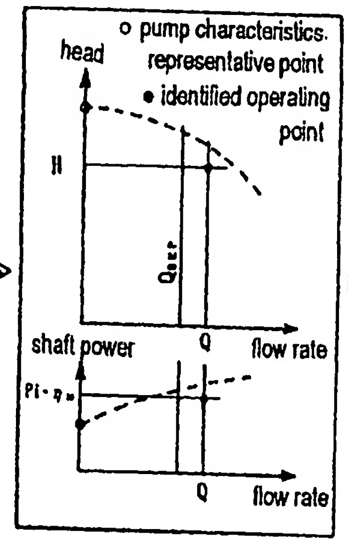

F I G. 29A

provisional pump characteristics



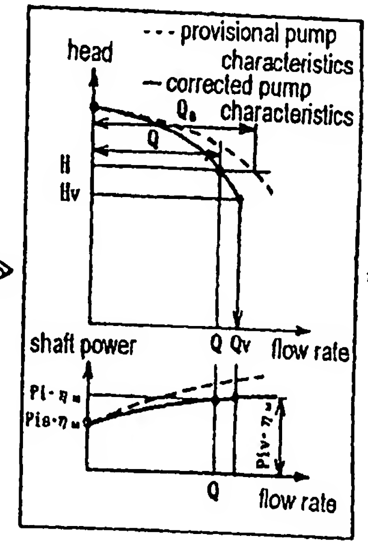

F I G. 29B

flow rate identification




F I G. 29C

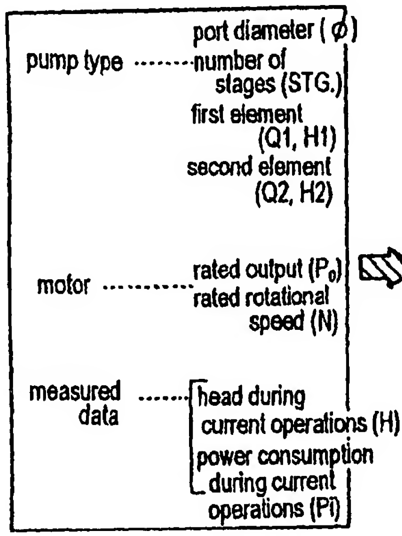
identifying pump characteristics




F I G. 29D

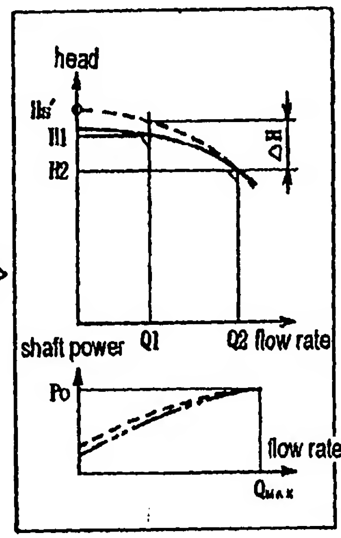
estimating pump characteristics · operating point

INPUT



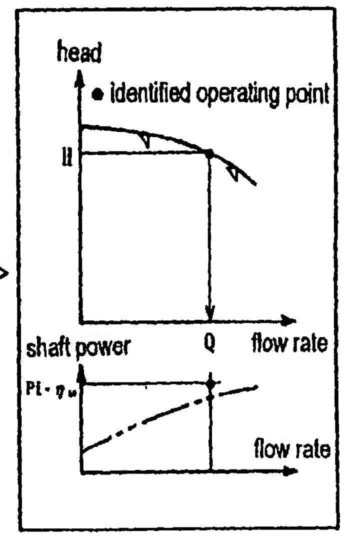

F I G. 30A

provisional pump characteristics



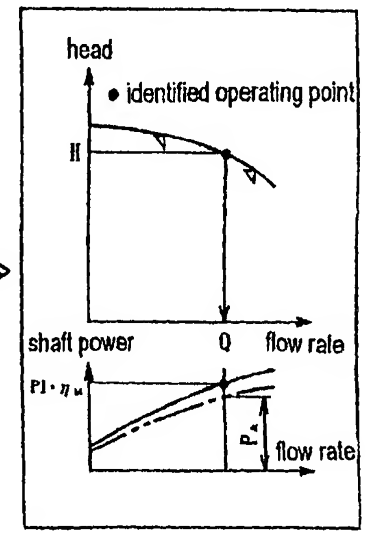

F I G. 30B

flow rate identification




F I G. 30C

identifying pump characteristics




F I G. 30D

estimating pump characteristics · operating point

INPUT

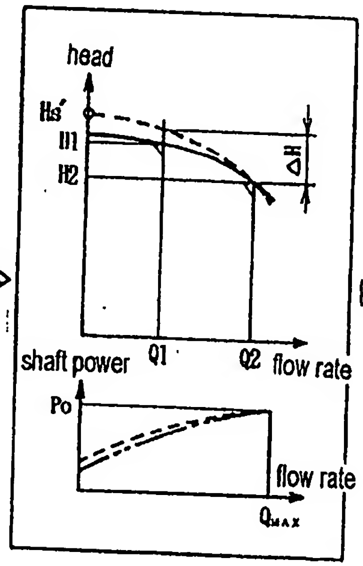
pump type ······· port diameter ($\phi$)
number of stages (STG.)
first element (Q1, H1)
second element (Q2, H2)

motor ·········· rated output ($P_0$)
rated rotational speed (N)

• measured data ········ head during current operations (H)
power consumption during current operations (Pi)
head during operations when the valve is fully open ($H_V$)
power consumption during operations when the valve is fully open (Piv)

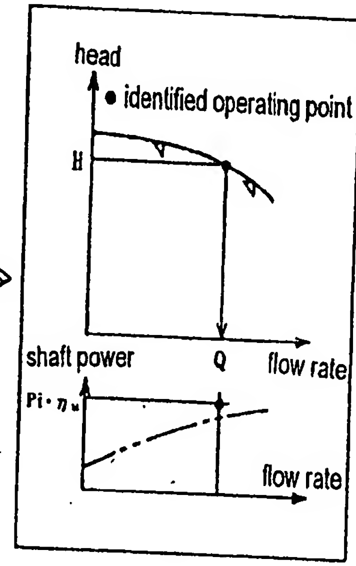
F I G. 3 1 A

provisional pump characteristics



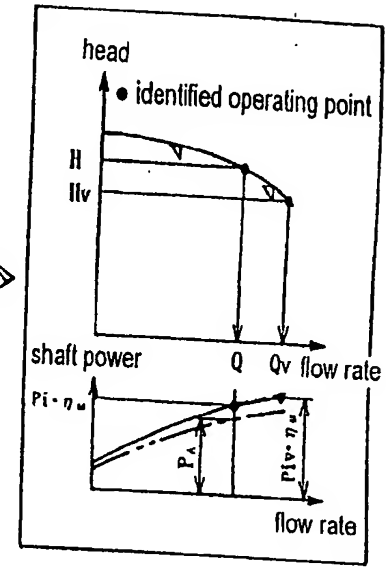

F I G. 3 1 B

flow rate identification



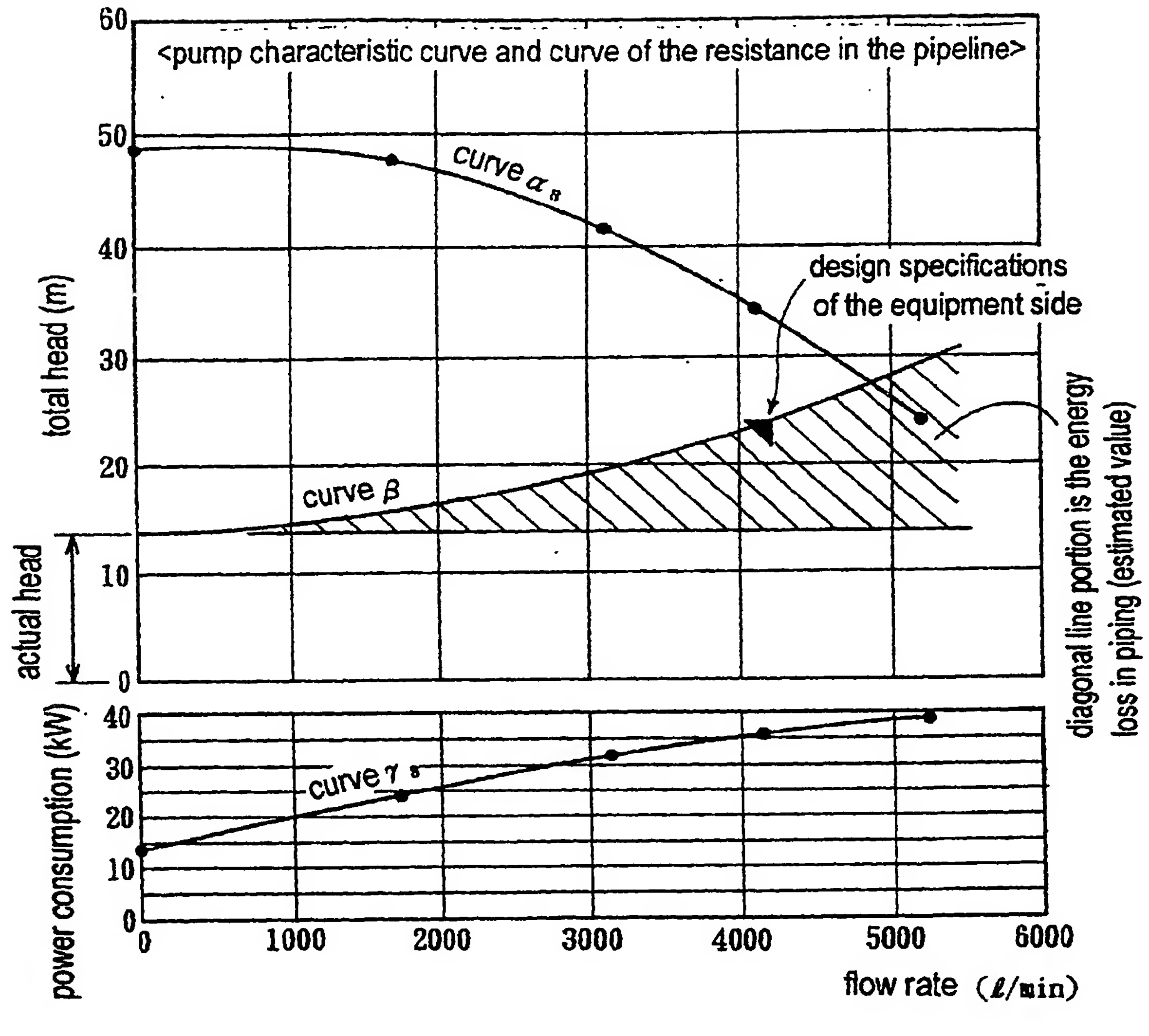

F I G. 3 1 C

identifying pump characteristics



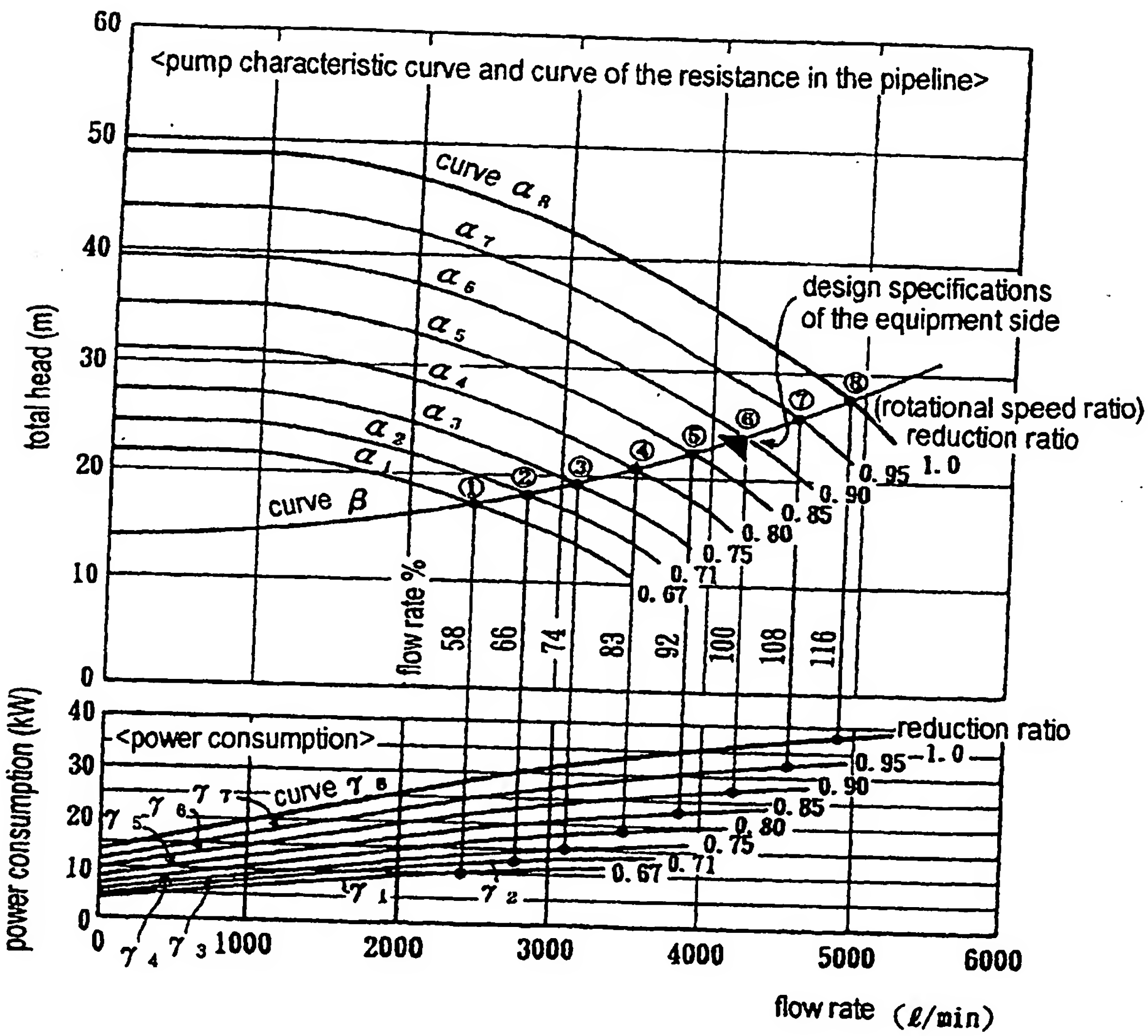

F I G. 3 1 D

F I G. 32



<pump characteristic curve and curve of the resistance in the pipeline>
60
50
40
30
20
10
0
total head (m)
actual head
curve $\alpha_8$
curve $\beta$
design specifications of the equipment side
diagonal line portion is the energy loss in piping (estimated value)
power consumption (kW)
40
30
20
10
0
curve $\gamma_8$
0
1000
2000
3000
4000
5000
6000
flow rate (ℓ/min)

F I G. 3 3



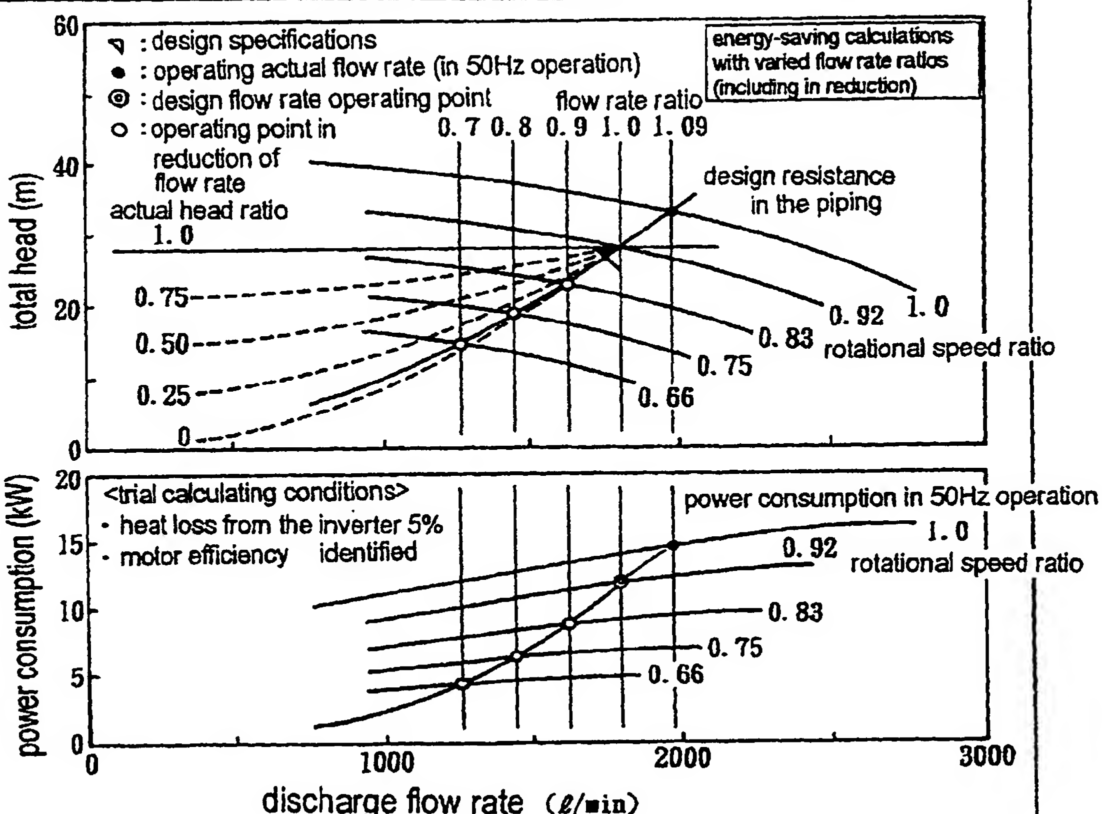
<pump characteristic curve and curve of the resistance in the pipeline>
total head (m)
60
50
40
30
20
10
0
curve α8
α7
α6
α5
α4
α3
α2
α1
curve β
design specifications of the equipment side
(rotational speed ratio) reduction ratio
0.95
1.0
0.90
0.85
0.80
0.75
0.71
0.67
flow rate %
58
66
74
83
92
100
108
116
<power consumption>
power consumption (kW)
40
30
20
10
0
reduction ratio
0.95
1.0
0.90
0.85
0.80
0.75
0.71
0.67
curve γ8
γ7
γ6
γ5
γ4
γ3
γ2
γ1
0
1000
2000
3000
4000
5000
6000
flow rate (ℓ/min)

F I G. 3 4

10

to [ / ] energy-saving pre-diagnostic system for the pump No. A0002

| | | | |
|---|---|---|---|
| Use | Circulation | Pump name | Cooling water circulating pump |
| Installation site | Outside | Pump maker | |
| Design specifications | 1800l/min × 28m × 3000min⁻¹ × 15kW | Model name | 100x80FS2G515 |
| Operating time | 24h/day × 350day/year | motor | 2P 15kW (output) |




A

<remarks>

# F I G. 3 5

<reduction calculation ratio of power consumption>

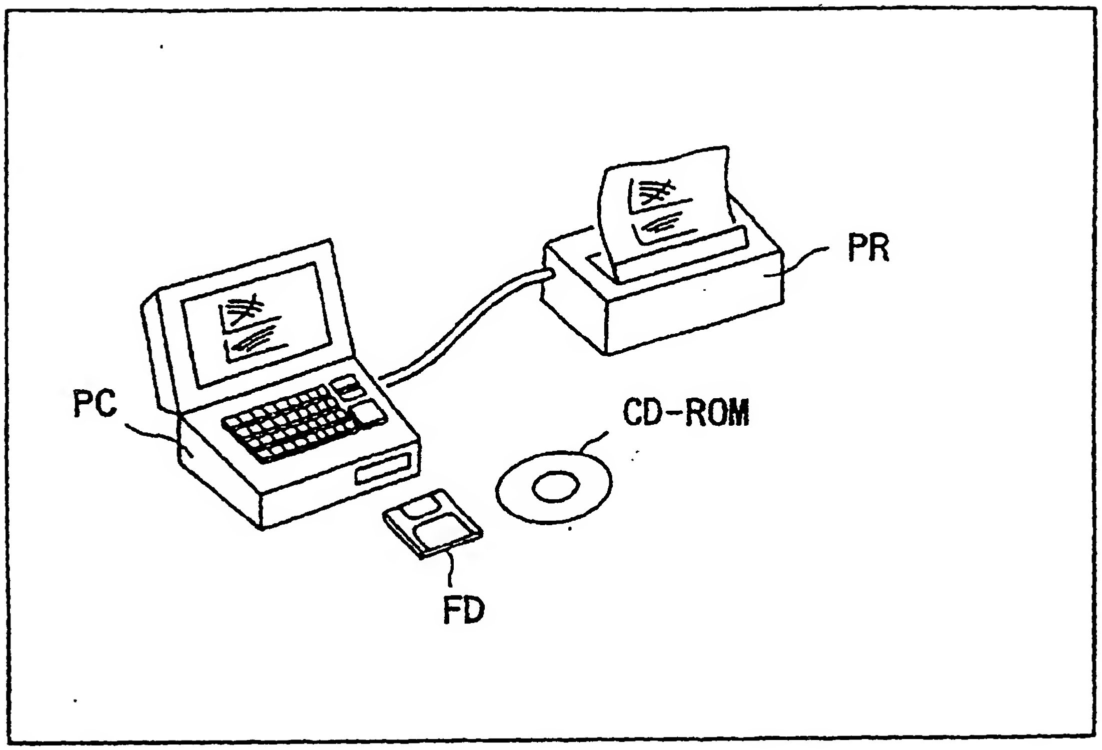
*1 source of coefficient program of the environmental action assessment (by Environmental Agency) September, 1996.

*2 reduced power cost is calculated using the unit price 13 yen/kWh.

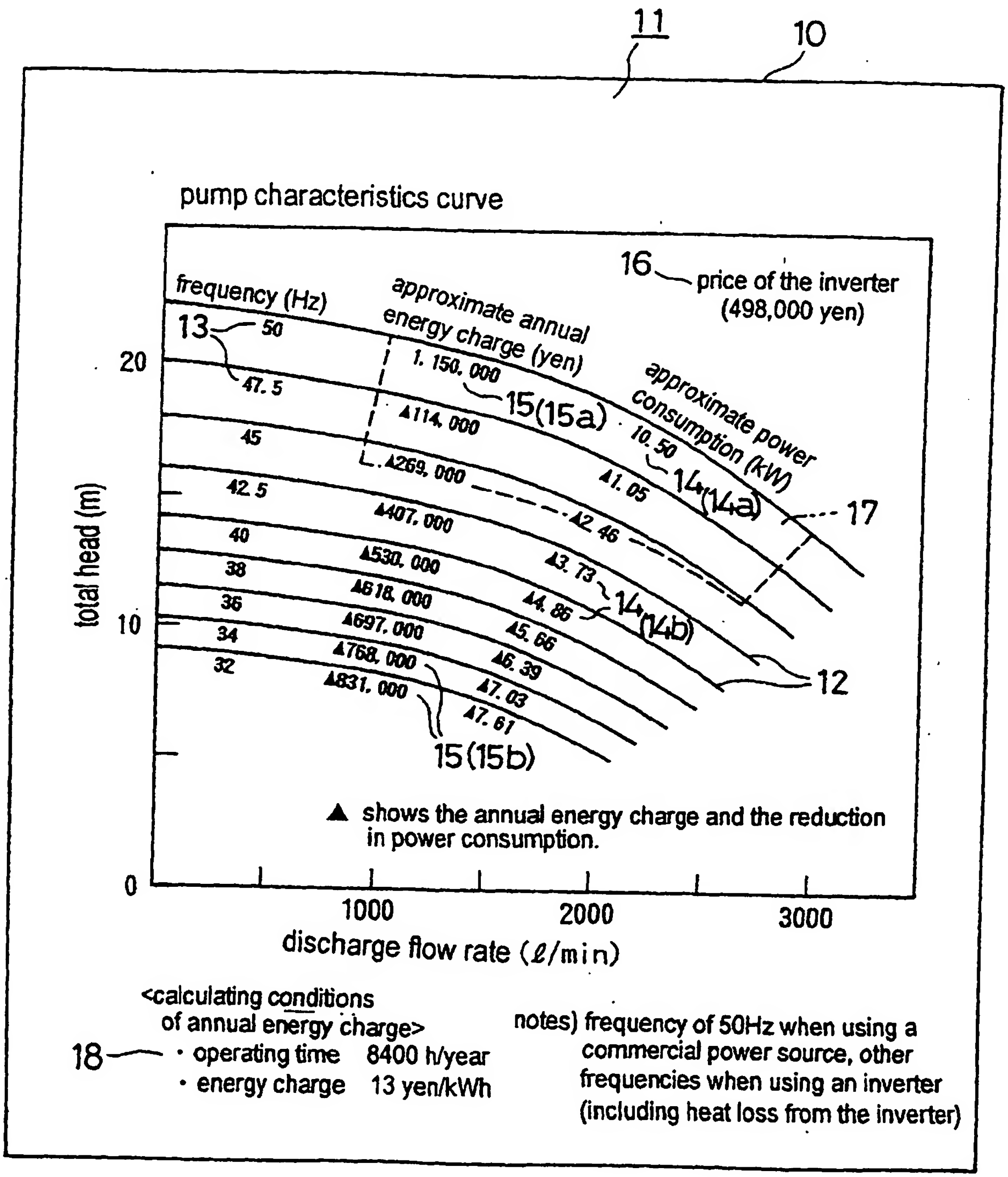
| flow rate (ℓ/min) ( ) is ratio to design value | | | rotational speed (ratio) | power consumption (kW) | the amount of power consumption (kWh/year) | $CO_2$ emissions *1 (t $CO_2$/year) | reduction of power consumption (kWh/year) | *2 reduced power consumption (yen/year) | reduction ratio (electric energy · $CO_2$ · electric power cost) |
|---|---|---|---|---|---|---|---|---|---|
| operating actual flow rate | | 1970 (1.09) | 1.0 | 14.7 | 123000 | 47 | 0 | 0 | 0% |
| design flow rate operating point | | 1800 (1.0) | 0.92 | 12 | 101000 | 39 | 22000 | 286,000 | 18% |
| in case of reduction of flow rate | -10% | 1620 (0.9) | 0.83 | 8.79 | 73800 | 28 | 49200 | 639,600 | 40% |
| | -20% | 1440 (0.8) | 0.75 | 6.44 | 54100 | 21 | 68900 | 895,700 | 56% |
| | -30% | 1260 (0.7) | 0.66 | 4.37 | 36700 | 14 | 86300 | 1,121,900 | 70% |

F I G. 3 6

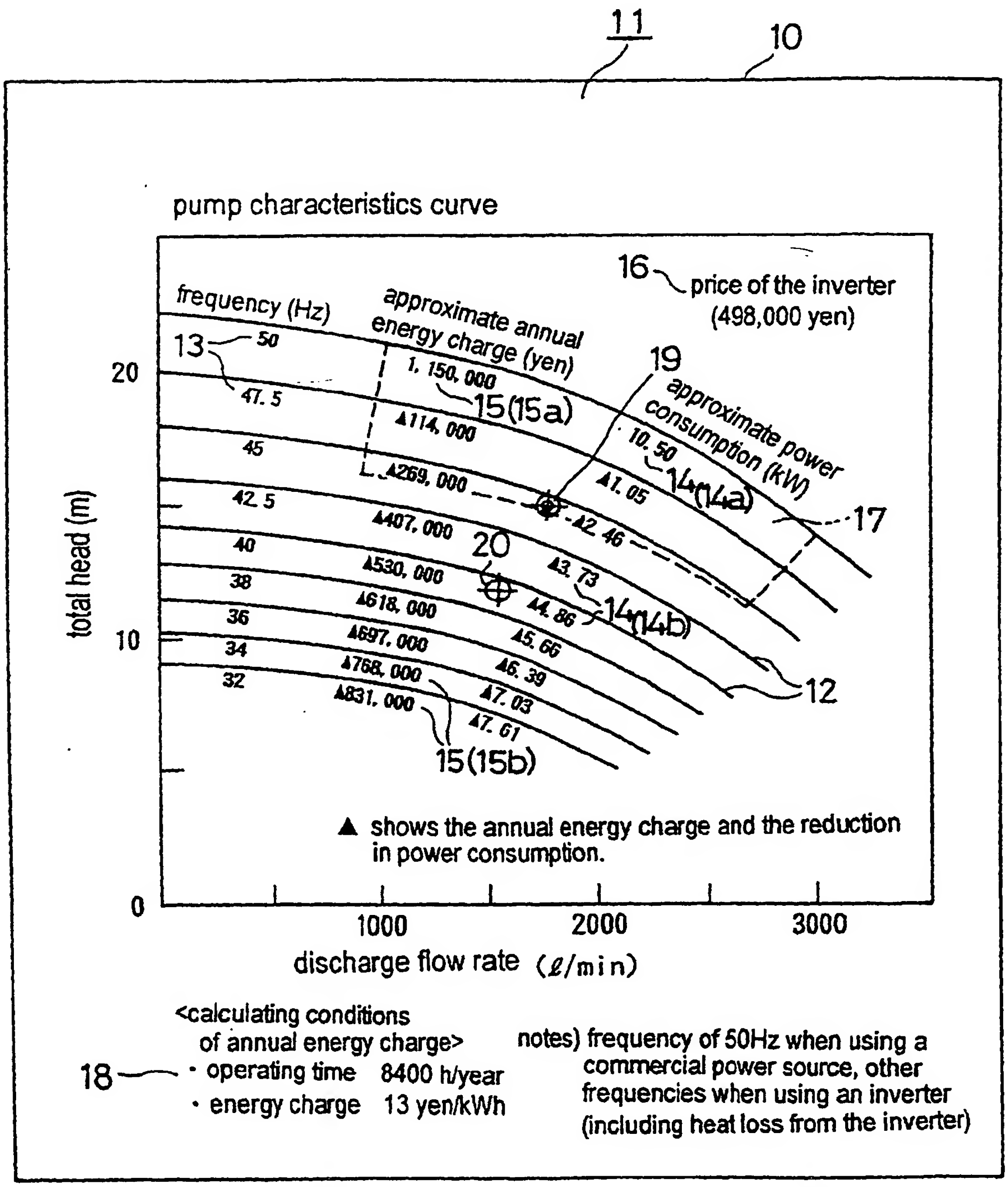
personal computer and recording medium



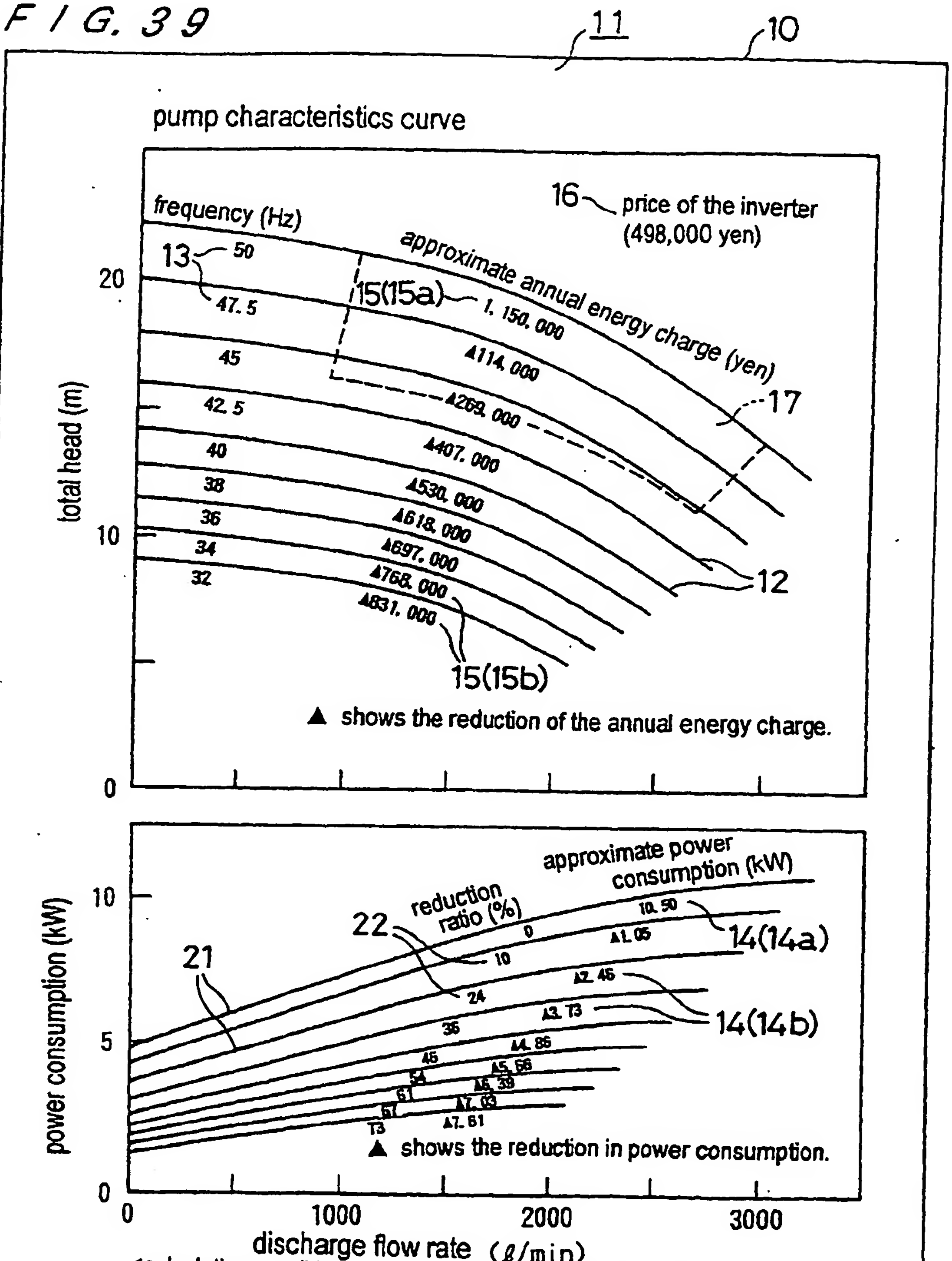
F I G. 3 7


11
10
pump characteristics curve
16
price of the inverter (498,000 yen)
frequency (Hz)
approximate annual energy charge (yen)
approximate power consumption (kW)
13
50
47.5
45
42.5
40
38
36
34
32
1. 150. 000
▲114. 000
▲269. 000
▲407. 000
▲530. 000
▲618. 000
▲697. 000
▲768. 000
▲831. 000
15(15a)
15(15b)
10. 50
▲1. 05
▲2. 46
▲3. 73
▲4. 86
▲5. 66
▲6. 39
▲7. 03
▲7. 61
14(14a)
14(14b)
17
12
total head (m)
20
10
0
1000
2000
3000
discharge flow rate (ℓ/min)
▲ shows the annual energy charge and the reduction in power consumption.
<calculating conditions of annual energy charge>
18
・operating time 8400 h/year
・energy charge 13 yen/kWh
notes) frequency of 50Hz when using a commercial power source, other frequencies when using an inverter (including heat loss from the inverter)

F / G. 3 8


11
10
pump characteristics curve
16
price of the inverter (498,000 yen)
frequency (Hz)
approximate annual energy charge (yen)
13
50
47.5
45
42.5
40
38
36
34
32
1, 150, 000
15(15a)
▲114, 000
▲269, 000
▲407, 000
▲530, 000
▲618, 000
▲697, 000
▲768, 000
▲831, 000
15(15b)
19
approximate power consumption (kW)
10.50
14(14a)
▲1.05
▲2.46
▲3.73
▲4.86
14(14b)
▲5.66
▲6.39
▲7.03
▲7.61
17
20
12
total head (m)
20
10
0
1000
2000
3000
discharge flow rate (ℓ/min)
▲ shows the annual energy charge and the reduction in power consumption.
<calculating conditions of annual energy charge>
18
・operating time 8400 h/year
・energy charge 13 yen/kWh
notes) frequency of 50Hz when using a commercial power source, other frequencies when using an inverter (including heat loss from the inverter)

F I G. 3 9




<calculating conditions of annual energy charge>

18 • operating time 8400 h/year

• energy charge 13 yen/kWh

notes) frequency of 50Hz when using a commercial power source, other frequencies when using an inverter (including heat loss from the inverter)

F I G. 4 0

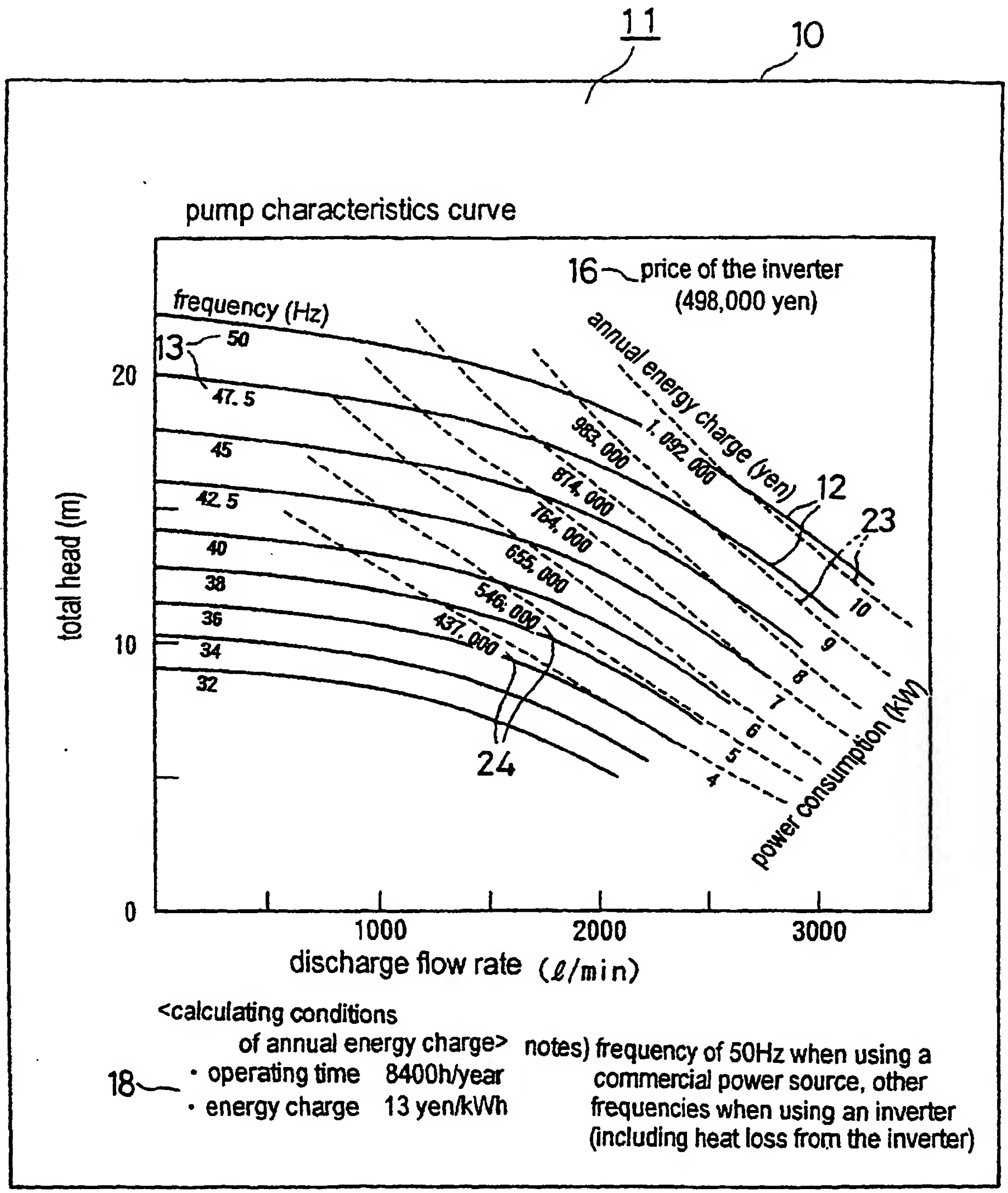

11
10
pump characteristics curve
16 price of the inverter
(498,000 yen)
frequency (Hz)
13
50
47.5
45
42.5
40
38
36
34
32
annual energy charge (yen)
1,092,000
983,000
874,000
764,000
655,000
546,000
437,000
12
23
24
10
9
8
7
6
5
4
power consumption (kW)
total head (m)
20
10
0
1000
2000
3000
discharge flow rate (ℓ/min)
<calculating conditions
of annual energy charge>
18
・operating time 8400h/year
・energy charge 13 yen/kWh
notes) frequency of 50Hz when using a commercial power source, other frequencies when using an inverter (including heat loss from the inverter)

FIG. 41

data regarding the flow rate-head characteristics and the flow rate-power consumption characteristics for the rotational speed of fluid machinery is inputted

step 1

calculations are performed to find the flow rate-head characteristics and the flow rate-power consumption characteristics for a plurality of rotational speeds different from the rotational speed inputted in step 1 (or measured data for various rotational speeds is inputted)

step 2

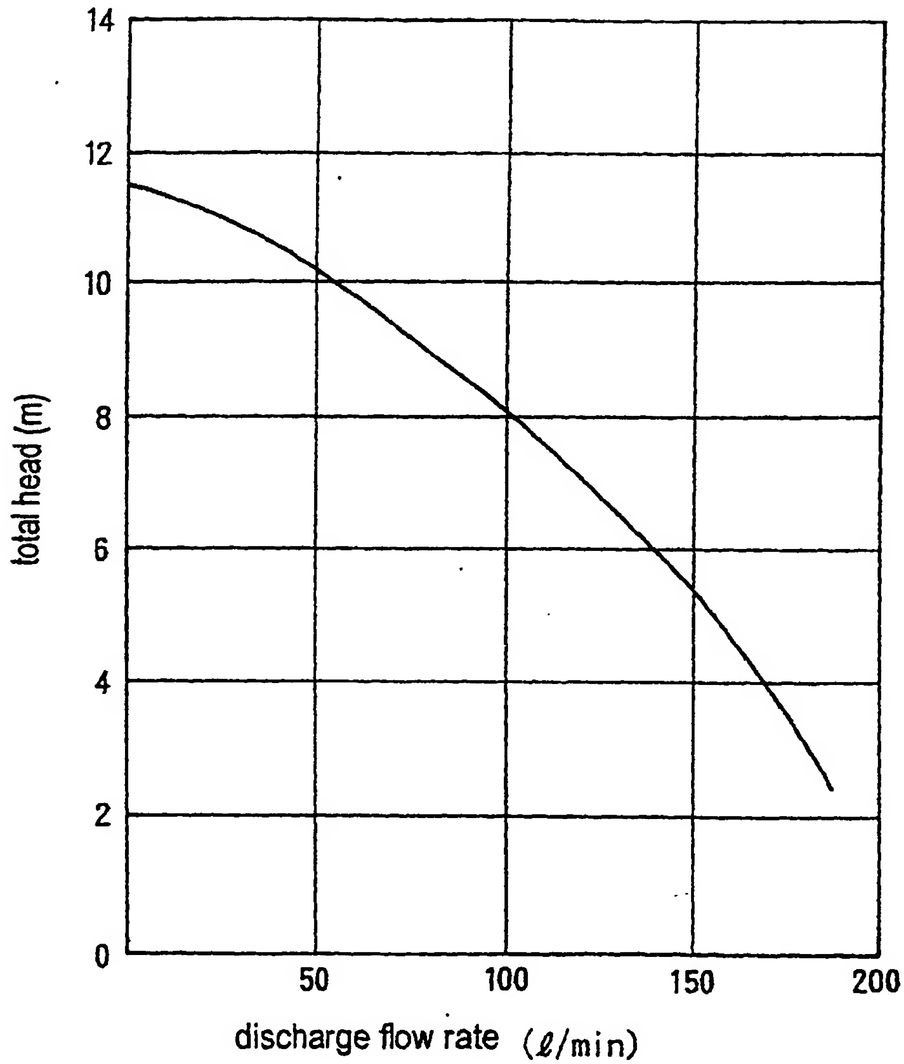
data regarding the operating time of the fluid machinery and the energy charge (per unit of power consumption) is inputted

step 3

a plurality of flow rate-head characteristic curves for various rotational speeds are displayed, along with data related to power consumption

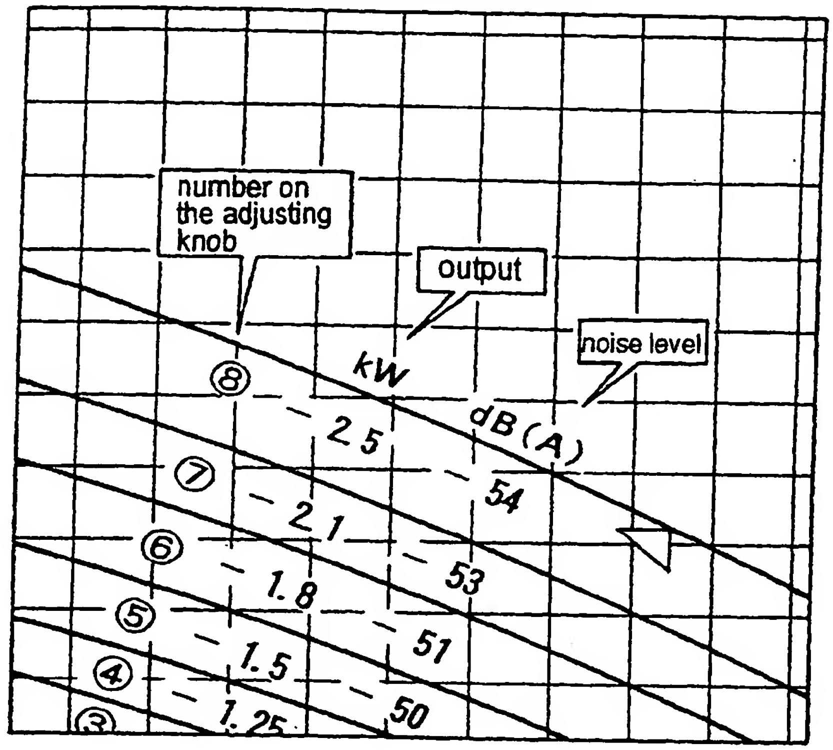
step 4

F I G. 42

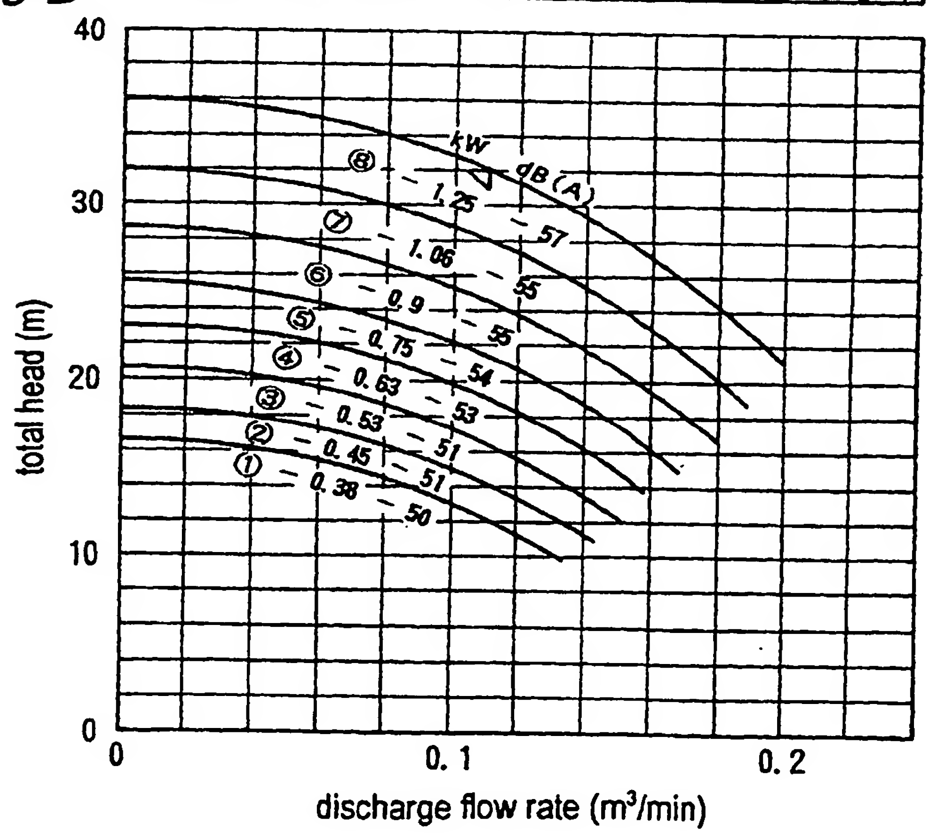

14
12
10
8
6
4
2
0
total head (m)
50
100
150
200
discharge flow rate (ℓ/min)

F I G. 4 3 A

explanatory graph of performance data




F I G. 4 3 B



## INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP99/01661

**A. CLASSIFICATION OF SUBJECT MATTER**
Int.Cl[6] F04B51/00

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)
Int.Cl[6] F04B51/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Jitsuyo Shinan Koho 1926-1996 Toroku Jitsuyo Shinan Koho 1994-1999
Kokai Jitsuyo Shinan Koho 1971-1995 Jitsuyo Shinan Toroku Koho 1996-1999

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| A | JP, 64-66481, A (Kawasaki Heavy Industries,Ltd.), 13 March, 1989 (13. 03. 89) (Family: none) | 1-32 |
| A | JP, 59-162395, A (Fuji Electric Co., Ltd.), 13 September, 1984 (13. 09. 84) (Family: none) | 1, 8-11, 20-22, 29, 30 |
| A | JP, 3-168386, A (Fuji Electric Co., Ltd.), 22 July, 1991 (22. 07. 91) (Family: none) | 1, 8-11, 20-22, 29, 30 |
| A | JP, 59-58317, A (Tokyo Shibaura Electric Co., Ltd.), 4 April, 1984 (04. 04. 84) (Family: none) | 1, 8-11, 20-22, 29, 30 |

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

| | |
|---|---|
| Date of the actual completion of the international search<br>1 July, 1999 (01. 07. 99) | Date of mailing of the international search report<br>21 July, 1999 (21. 07. 99) |
| Name and mailing address of the ISA/<br>Japanese Patent Office<br><br>Facsimile No. | Authorized officer<br><br>Telephone No. |

Form PCT/ISA/210 (second sheet) (July 1992)